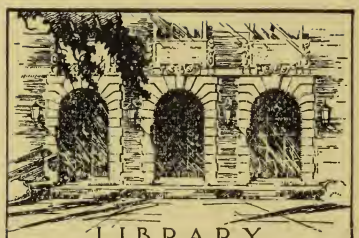

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TRANSACTIONS

OF THE

LIVERPOOL ENGINEERING SOCIETY.

VOL. XIX.

TWENTY-FOURTH SESSION.

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EDITED BY

R. C. F. ANNETT, ASSOC. INST. C.E.,

Honorary Secretary.

LIVERPOOL:

PUBLISHED BY THE SOCIETY,

ROYAL INSTITUTION, COLQUITT STREET.

1898

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LIVERPOOL ENGINEERING SOCIETY,

ROYAL INSTITUTION, COLQUITT STREET.

XXV SESSION.—1898-99.

COUNCIL.

In accordance with Rule V, this Council commence their duties on the first Wednesday in November, 1898.

President.

JOHN A. BRODIE, Wh. Sc., M. Inst. C.E., M. I. Mech.E.

Vice-Presidents.

A. BROMLEY HOLMES, M. Inst. C.E., M.I.E.E.

JOHN A. F. ASPINALL, M. Inst. C.E., M. I. Mech. E., M. I. and S. Inst.

Members of Council.

WILLIAM BRODIE.

FRED. E. COOPER,

CHAS. H. DARBISHIRE, J.P., Assoc. M. Inst. C.E.

THOMAS DUNCANSON, Assoc. M. Inst. C.E.

THOMAS L. MILLER, Assoc. M. Inst. C.E.

WILLIAM E. MILLS.

JAMES MORGAN, Assoc. M. Inst. C.E.

FRANK E. PRIEST, M. Inst. C.E.

J. RENEY SMITH, M.I. Mech E.

HENRY H. WEST, M. Inst. C.E., M.I.N.A., M.I. Mech. E.

ERNEST S. WILCOX, M. Inst. C.E.

JOHN T. WOOD, M. Inst. C.E.

Past-Presidents.

In accordance with Rule IV, Past Presidents are ex-officio Members of Council for five consecutive years after their retirement from Office.

H. PERCY BOULNOIS, M. Inst. C.E., 1893-94.

Dr. H. S. HELE-SHAW, M. Inst. C.E., 1894-95.

ARTHUR J. MAGINNIS, M.I.N.A., 1895-96.

S. B. COTTRELL, M. Inst. C.E., M. I. Mech. E., 1896-97.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S., 1897-98.

Honorary Librarian.

ARTHUR MUSKER, Assoc. M. Inst. C.E., M. I. Mech. E.,
Dundas Street, Bootle.

Honorary Treasurer.

COARD S. PAIN, Assoc. Inst. C.E., F.S.I.,
14, North John Street, Liverpool.

Honorary Secretary.

R. C. F. ANNETT, Assoc. Inst. C.E.,
Royal Institution, Colquitt Street, Liverpool.

NOTE—In accordance with Rule V, this Council will continue in Office until the first Wednesday in November, 1899.

LIVERPOOL ENGINEERING SOCIETY.

Past Presidents of the Society.

(1.)	1875-76 / 1877	C. Henry Graham Smith, Assoc. M. Inst. C.E.	(Died 9th Sept., 1884). See Memoir in Vol. LXXVIII. Proc. Inst. C.E.
(2.)	1878	Robinson Souttar, M.P., M.A., B.C.L. Oxon.	
(3.)	1879	M. E. Yeatman, M.A. Cantab., M. American S.C.E.	
(4.)	1880	Alexander Ross, M. Inst. C.E.	
(5.)	1881	Alfred Holt, M. Inst. C.E.	
(6.)	1882	Frank B. Salmon, M.I. and S. Inst.	
(7.)	1883	Henry Bramall, M. Inst. C.E.	
(8.)	1884	R. Ratsey Bevis, Junr.	
(9.)	1885	William E. Mills.	
(10.)	1886	Coard S. Pain, Assoc. Inst. C.E., F.S.I.	
(11.)	1887	John J. Webster, M. Inst. C.E.	
(12.)	1888	Chas. H. Darbishire, J.P., Assoc. M. Inst. C.E.	
(13.)	1889-90	Henry H. West, M. Inst. C.E., M. I. N. A., M. I. Mech. E.	
(14.)	1890-91	Ferdinand Hudleston, Assoc. M. Inst. C.E.	
(15.)	1891-92	John T. Wood, M. Inst. C.E.	
(16.)	1892-93	Robert E. Johnston, M. Inst. C. E.	
(17.)	1893-94	H. Percy Boulnois, M. Inst. C.E., F.S.I.	
(18.)	1894-95	H. S. Hele-Shaw, LL.D., M. Inst. C.E., M. I. Mech. E., F.R. Met. Soc.	
(19.)	1895-96	Arthur J. Maginnis, M. I. N. A., M. I. Mar. E.	
(20.)	1896-97	S. B. Cottrell, M. Inst. C.E., M.I. Mech. E.	
(21.)	1897-98	George Farren, J.P., M. Inst. C.E., F.R.S.S.	

Mr. GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,

President of the Liverpool Engineering Society,

XXIV Session—1897-98.

LIVERPOOL ENGINEERING SOCIETY.

REPORT.—XXIV SESSION.

1897-98.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S., President.

At the close of the Twenty-fourth Session the retiring Council have to present the following Report upon the state of the Society.

THE ROLL OF THE SOCIETY.

The additions to the Roll of the Society have been 26 compared with 49 in the previous Session, and include 2 Honorary Members, 19 Members, 3 Associates and 2 Students.

On the other hand, it has to be recorded that 6 names have been removed from the list as against 8 last year. Of the removals 1 is due to resignation and 5 to deaths. At the present date the number of Members of all classes is 383, as against 363 at the close of the previous year, being 10 Honorary Members, 8 Life Members, 1 Life Associate, 317 Ordinary Members, 27 Associates and 20 Students.

THE SESSION AND MEETINGS.

The past Session was opened on the 3rd November, 1897, by the President, Mr. George Farren, J.P., M. Inst. C.E., F.R.S.S., who delivered his Inaugural Address before a full audience of members and their friends. He took for his text exactness in measurement—exactness of facts—exactness of statement—exactness in inference and in reasoning powers.

He incidentally alluded to the doctrine of probabilites as founded absolutely on exact statements, and especially those relating to reasoning power and inference.

He then drew attention to several remarkable cases of exactitude, and the enormous difficulty that many hard workers in the profession have cheerfully faced and conquered.

On the other hand he drew attention to the want of exactitude especially in dealing with other large questions, and incidentally alluded to the slowness of the human intellect in assimilating well known facts.

This was succeeded at subsequent meetings by papers and discussions upon the various Engineering subjects enumerated in the following summary :—

1897.

17th November.—Mr. SHERARD COWPER-COLES, Assoc. M. Inst. C.E., M. I. Mech. E.—
"Electro-Zincing."

1st December.—Mr. PROSSER A. H. SHAW, M. Inst. C.E.—
"Portland Cement."

1st December.—Mr. FRANK E. PRIEST, M. Inst. C.E.—
"Experiments in the Acceleration of the Setting of Portland Cement."

15th December.—Discussion upon the two foregoing Papers.

1898.

5th January.—Mr. J. WALWYN WHITE.—
"Aerial Rope Railways, with special reference to Traffic between Liverpool and Manchester."

19th January.—Mr. SEYMOUR B. TRITTON, M. Inst. C.E., M.I.N.A.—
"Shallow Draught Steamers."

2nd February.—Dr. H. S. HELE-SHAW, M. Inst. C.E., M. I. Mech. E.—
"Experiments on the Flow of Water."

16th February.—Discussion on Dr. H. S. Hele-Shaw's Paper.

2nd March.—Dr. J. H. T. TUDSBERY, M. Inst. C.E.—
"Engineering Survey Work."

16th March.—Prof. OLIVER J. LODGE, D. Sc., F.R.S.—
"Telegraphy by Electric Waves across Space."

30th March.—Mr. A. W. BRIGHTMORE, M. Sc., M. Inst. C.E.—
"The Masonry Dam Problem."

13th April.—Nomination of Council and Officers for the next Session.
Mr. HUGH ROGERS.—
"Liverpool Landing Stage Extension and Prince's Jetty."

27th April.—ANNUAL GENERAL MEETING.
Mr. ANDREW HAMILTON, M.I.N.A.—
"Diagrams as Illustrating Ship and Engine Performances."

The Trustees of the "West Premium," on the recommendation of the Committee appointed by the Council, awarded the Premium for the previous Session to Mr. WILLIAM BRODIE, *Member*, for his paper entitled "Dock Gates."

ANNUAL DINNER.

The Annual Dinner of the Society took place at the Adelphi Hotel, Liverpool, on the evening of Thursday, the 20th January, 1898. About 150 members supported the President on that occasion. The Society's guests included, amongst others, the Right Hon. The Lord Mayor of Liverpool (Mr. Alderman John Houlding, J.P.), Sir Wm. H. White, K.C.B., Chief Director Naval Construction, Sir Gilbert Carter, Governor of the Bahamas, Mr. Charles McArthur, M.P., Sir Edward Russell, Mr. Alfred L. Jones, J.P., Admiral Gough, R.N., C.B., J.P., Mr. F. C. Danson, President of the Chamber of Commerce, Mr. H. H. Gibbons, President of the Incorporated Law Society, Mr. W. E. Willink, C.C., President of the Liverpool Architectural Society.

EXCURSIONS DURING 1897.

Through the courtesy of the respective Engineers and Authorities excursions were made to the following works, viz. :—

26th June.—Manchester Cold Storage Works.
(Mr. M. C. Bannister, Assoc. M. Inst. C.E., Consulting Engineer.)

17th July.—Penmaenmawr Quarries and Works.
(Mr. Chas. H. Darbishire, J.P., Assoc. M. Inst. C.E., Managing Director.)

2nd Aug.—Birmingham Corporation Water Works.
(Mr. Jas. Mansergh, M. Inst. C.E., Chief Engineer.)

25th Sept.—Extension Works of the Generating Station, Liverpool Overhead Railway Company.
(Mr. S. B. Cottrell, M. Inst. C.E., Past President of the Society, Engineer and General Manager; Messrs. Holme & King, Contractors.)

The thanks of the Council have been duly communicated to the respective authorities.

OBITUARY.

The Council have to regret the deaths of four Members and one Student, viz., Mr. Horace V. Broomfield, Mr. P. W. Johnson, Mr. Thomas Morris, F.G.S., Mr. C. Warren Roberts, Assoc. M. Inst. C.E., and Mr. W. L. Bomford.

RECEIPTS AND EXPENDITURE.

In accordance with Rule VI, the Honorary Treasurer's Financial Statement of Accounts for the year ending 31st December, 1897, has been duly audited, and is presented herewith.

The following statement shows a comparison of the Receipts and Expenditure for the past two years apportioned to the respective headings of account as published by the Honorary Treasurer in his Annual Statement :—

RECEIPTS.	1896.	1897.	EXPENDITURE.	1896.	1897.
Subscriptions ..	£268 0 3	£260 13 3	Rent and attendance	£20 0 0	£23 0 0
Sale of Transactions	1 15 0	3 15 0	Stationery, Postage, and Telegrams ..	28 1 1	30 18 1
Tickets for Annual Dinner	149 2 0	147 0 0	Printing	124 2 1	194 11 7
Interest	4 17 7	5 4 5	Annual Dinner ..	158 17 8	143 16 4
	£423 14 10	£416 12 8	Salary of Assistant Secretary	35 0 0	38 15 0
			Sundries	0 9 2	0 10 11
				£366 10 0	£431 11 11
Balances brought forward	193 14 6	250 19 4	Balances carried forward	250 19 4	236 0 1
	£617 9 4	£667 12 0		£617 9 4	£667 12 0

GROWTH OF THE SOCIETY.

The following Table shows the progress made by the Society since its commencement in 1875 :—

Year	Honorary Members	Ordinary Members	Associates	Students	Total	New Members Elected	Deaths, Resignations and Erasures	Nett Increase	President for each Session
1875-76	—	51	—	—	51	—	—	—	C. H. G. Smith
1877	3	68	—	—	71	20	—	20	
1878	3	82	—	—	85	17	3	14	Robinson Souttar
1879	3	73	—	—	76	4	13	—	M. E. Yeatman
1880	3	88	—	—	91	23	8	15	Alexander Ross
1881	4	93	—	—	97	18	12	6	Alfred Holt
1882	5	88	—	11	104	10	3	7	Frank B. Salmon
1883	5	96	—	8	109	10	5	5	Henry Bramall
1884	5	99	—	6	110	16	15	1	R. Ratsey Bevis
1885	5	109	—	4	118	19	11	8	William E. Mills
1886	5	120	—	11	136	28	10	18	Coard S. Pain
1887	7	144	—	15	166	32	2	30	John J. Webster
1888	6	151	—	18	175	30	21	9	C. H. Darbishire
1889-90	6	169	1	16	192	33	16	17	Henry H. West
1890-91	6	181	3	9	199	20	13	7	F. Hudleston
1891-92	5	191	6	11	213	19	5	14	John T. Wood
1892-93	3	219	8	10	240	35	8	27	R. E. Johnston
1893-94	2	221	11	13	247	29	22	7	H. P. Boulnois
1894-95	4	238	11	21	274	41	14	27	H. S. Hele-Shaw
1895-96	6	278	18	20	322	61	13	48	A. J. Maginnis
1896-97	8	311	25	19	363	49	8	41	S. B. Cottrell
1897-98	10	325	28	20	383	26	6	20	George Farren

THE LIBRARY.

During the past Session, the Honorary Librarian, Mr. Arthur Musker, Assoc. M. Inst. C.E., M. I. Mech. E., has prepared a valuable Catalogue of the various books in the Society's Library, copies of which will be bound up with the Society's Transactions for the past Session. This will also contain an index of the Society's Transactions from the commencement to the present date.

The following publications have been received during the year :—

From the respective authors—"Torquay Waterworks," (paper) by W. Ingham, Water Engineer, Torquay; "Water Supply and Collateral Works," (paper) by Dr. J. H. T. Tudsbery, *Member*, M. Inst. C.E.

From the editors and proprietors—"American Engineer and Railroad Journal"; "British Architect"; "Mechanical Engineer"; "Engineering Magazine"; "Cassier's Magazine"; "Indian Engineering"; "Steamship"; "Engineer's Gazette"; Transport."

And also—"Annual Report, Chief of Engineers," U.S. Army, 1896; "Digest of Physical Tests and Laboratory Practice" from F. A. Riehlé, Philadelphia.

The Society exchanges Transactions with—

1. American Association for the Advancement of Science
2. American Institution of Electrical Engineers
3. American Institution of Mining Engineers
4. American Society of Civil Engineers
5. American Society of Mechanical Engineers

Association of Engineering Societies, consisting of:—

6. Boston Society of Civil Engineers
7. Civil Engineers' Club of Cleveland
8. Civil Engineers' Club of St. Louis
9. Civil Engineers' Society of St. Paul
10. Engineers' Club of Kansas City
11. Minneapolis Society of Civil Engineers
12. Montana Society of Civil Engineers
13. Western Society of Engineers
14. Association of Engineers of Virginia
15. Association of Municipal and County Engineers
16. British Association for the Advancement of Science
17. British Association of Waterworks Engineers.
18. Canadian Society of Civil Engineers
19. Chesterfield and Midland Counties Institution of Engineers
20. Civil and Mechanical Engineers' Society
21. École d'application du Genie Maritime, Paris
22. Engineers' Club of Philadelphia
23. Engineering Society Western Pennsylvania
24. Franklin Institute
25. Hull and District Institution of Engineers and Naval Architects
26. Institute of Marine Engineers
27. Institution of Civil Engineers
28. Institution of Civil Engineers of Ireland
29. Institution of Electrical Engineers
30. Institution of Engineers and Shipbuilders in Scotland
31. Institution of Junior Engineers
32. Institution of Mechanical Engineers
33. Institution of Naval Architects
34. Iron and Steel Institute
35. Liverpool Architectural Society
36. Liverpool Chemists' Association
37. Liverpool Geological Association
38. Liverpool Geological Society
39. Liverpool Literary and Philosophical Society
40. Liverpool Naturalists' Field Club
41. Liverpool Philomathic Society
42. Liverpool Polytechnic Society
43. Manchester Association of Engineers
44. Manchester Literary and Philosophical Society
45. Midland Institute of Civil & Mechanical Engineers
46. Mining Association and Institute of Cornwall
47. Mining Institute of Scotland
48. North-East Coast Institution of Engineers and Shipbuilders
49. North of England Institute of Mining and Mechanical Engineers
50. North Staffordshire Institute of Mining and Mechanical Engineers
51. North Western Sanitary Inspectors' Association.
52. Philosophical Society of Glasgow
53. Rensselaer Society of Engineers
54. Royal Geological Society of Cornwall
55. Royal Institution of Cornwall
56. Royal Physical Society of Edinburgh
57. Smithsonian Institution
58. Society of Arts of the Massachusetts Institute of Technology
59. Society of Engineers
60. South Wales Institute of Engineers
61. Stevens Institute of Technology
62. Technical Society of the Pacific Coast
63. University of California
64. Warrington Literary and Philosophical Society
65. Yorkshire College Engineering Society

The Transactions of the Society are presented to—

66. "American Engineer and Railroad Journal"
67. Bootle Free Public Library
68. "British Architect"
69. Chief of Engineers U.S. Army
70. "Engineer"
71. Engineering Department, University College, Liverpool
72. "Engineering"
73. "Indian Engineering"
74. "Mechanical Engineer."
75. Liverpool Free Public Library
76. Patent Office Library
77. "Steamship"
78. University of Minnesota

Total Number of Transactions exchanged with, and presented to, other Societies = 78.

LIVERPOOL ENGINEERING SOCIETY.

Dr. STATEMENT of RECEIPTS and EXPENDITURE to the 31st DECEMBER, 1897. Cr.

RECEIPTS.

			£ s. d.
To Balance from preceding year, 1896			81 7 4
" Subscriptions due 1st January, 1897—			
1 Life Member's Subscription	£10 10 0		
195 Resident Members' Subscriptions	204 15 0		
106 Non-Resident Members' Subscriptions	55 13 0		
18 Resident Associates' Subscriptions	18 18 0		
6 Non-Resident Associates' "	3 3 0		
19 Students' Subscriptions	9 19 6		
		£302 18 6	
" Arrears from last Account		87 2 0	
		390 0 6	
Less received in advance in 1896	17 17 0		
" Arrears carried to 1898 Account	116 15 3		
" " now written off	5 15 6		
		140 7 9	
		249 12 9	
" Subscriptions for 1898, received in advance		11 0 6	
			260 13 3
" Sale of Transactions			3 15 0
" " Tickets for Annual Dinner, 1897			147 0 0
" Interest on £150 L. & Y. Railway 3 % debentures			4 7 0
" Banker's Interest for 1897			0 17 5
Total			£498 0 0

EXPENDITURE.

		£ s. d.
By Royal Institution Rent to February 13th, 1898, paid in advance		20 0 0
" Attendance to September 14th, 1896		3 0 0
" Postage and Telegrams (including Correspondence, Notices, Transactions, &c.) also Stationery, Official Books, &c.		30 18 1
" General Printing of Notices of Meetings, Dinner, Excursions, Annual Reports, &c.		68 13 3
" Printing, Illustrating, and Binding Transactions (Volume XVIII)		125 18 4
" Annual Dinner, 1897		143 16 4
" Salary of Assistant Secretary to September 30th, 1897		38 15 0
" Banker's Commission for year 1897		0 10 11
" Balances—In Liverpool Union Bank	£33 0 0	
" " hands of Hon. Treasurer	29 8 0	
" " hands of Assistant Secretary	4 0 1	
		66 8 1
Total		£498 0 0

Investment Account: £150 Lancashire & Yorkshire Railway 3 % debenture stock (costing £169 12s.).

(*Signed*) MALCOLM BLAIR, F. E. COOPER, } AUDITORS.

27th April, 1898

COARD S. PAIN,
Hon. Treasurer.

LIVERPOOL ENGINEERING SOCIETY.

ESTABLISHED NOVEMBER 10th, 1875.

Rules and Regulations. Amended 14th April, 1897.

OBJECT.

The promotion of the study and practice of Engineering.

RULE I.

Constitution.

The Society shall consist of Honorary Members, Ordinary Members, Associates, and Students.

Honorary Members shall be men of eminent scientific attainments, whom the Society shall deem worthy of the distinction.

Ordinary Members shall be persons who shall have been regularly educated as Engineers according to the usual routine of pupilage or apprenticeship, and who shall be actually engaged at the time of application for election in some responsible position in any branch of the profession of Engineering, or who shall in the opinion of the Council have attained such experience in some branch of the profession as to qualify them for Membership.

Associates shall be persons of more than 21 years of age, who are not Engineers by profession; but who, by their connection with science or the arts, are qualified to concur with Engineers in the advancement of professional knowledge. They shall have all the privileges of membership, except that they shall not be eligible for election to the Council otherwise than as Officers, nor shall they have a right to nominate candidates for election to the Society, or vote in General Meeting.

Students shall be persons under 21 years of age, in course of training to become Engineers. They shall have all the privileges of ordinary membership, but shall not have the right to vote or nominate candidates for election to the Society.

RULE II.

Admission of Members, Associates and Students.

Any person before being admitted into the Society, as an Ordinary Member or Associate, shall be proposed by a Member, recommended by two other Members, and elected at a Meeting of the Society by at least three-fourths of the Members voting.

The proposal for Members and Associates shall be made on Form A, which shall be filled up and sent to the Secretary one week before the Meeting previous to that at which the Candidate is to be balloted for.

The proposal for Honorary Members shall be made on Form B, which shall be signed by a majority of the Members of Council.

The proposal for Students shall be on Form C, which shall be similar to Form A, with provision for stating the age of the Candidate.

The Council shall examine the proposal forms, and both on the evening of proposal and ballot the Secretary shall state that they have been so examined.

RULE III.

Members or Associates residing or being engaged in a place of business within 10 miles of the Liverpool Exchange shall be considered Resident Members or Associates, those beyond such limits Non-resident Members or Associates. Residence.

The Subscription shall be for each Resident Ordinary Member or Associate One Guinea per annum; for each Non-resident Ordinary Member or Associate and for each Student, Half-a-Guinea per annum. Subscriptions.

Subscriptions are payable on each first of January for the year ensuing, or, in the case of new Members, within one month of their election, excepting those elected in any year during the month of November, when their subscription shall not be due until the 1st of January following.

Any Member or Associate may compound for the Annual Subscription by the payment of Ten Guineas, and so become a Life Member or Life Associate.

Any Member, Associate, or Student not paying his Subscription within three calendar months after a second notification by the Secretary that it is due, shall be considered no longer a Member of the Society.

RULE IV.

The Council of the Society shall consist of a President, two Vice Presidents, and twelve other Members, and they, together with the *ex-officio* Members of Council, shall manage the affairs of the Society. Council and Officers.

Past Presidents shall be *ex-officio* Members of the Council for five consecutive years after their retirement from office. Past Presidents.

Four shall form a quorum. Quorum.

The officers of the Society shall be an Honorary Secretary, an Honorary Treasurer and an Honorary Librarian, and they shall be *ex-officio* Members of the Council. Officers.

The President shall take the chair at all meetings of the Society and the Council at which he is present, and shall regulate and keep order in the proceedings. President.

In the absence of the President, it shall be the duty of one of the Vice-Presidents to preside.

In the event of the absence of the President and Vice-Presidents, the Members present shall elect a Chairman from amongst themselves. Vice-Presidents.

The Honorary Secretary shall act under the Direction of the Council, and shall conduct the correspondence of the Society, take minutes of the Proceedings at all meetings, and enter them in the Minute Books, read the Minutes and Notices at all meetings, revise and edit the Transactions, and keep a Register of the Members of the Society. Honorary Secretary.

The Honorary Treasurer shall collect all sums due to the Society, and pay the same into one of the Liverpool Banks to the credit of the Society. He shall pay all sums due by the Society, by cheque, signed by two Members of the Council, and keep an account of the income and expenditure in a General Cash Book provided for the purpose; such Cash Book shall be open for inspection by the Council at any Council Meeting. He shall produce, at the last Meeting of the Council in each year, a Balance Sheet or Financial Statement, together with an inventory of all property possessed by the Council. Honorary Treasurer.

The Honorary Librarian shall receive and be responsible for the whole of the books, papers, drawings, models, &c., belonging to the Society. He shall keep a catalogue of all such books, papers, &c., and shall lend them to the Members, under regulations to be sanctioned by the Council. Honorary Librarian.

RULE V.

Election of Council and Officers.

The Council and Officers of the Society shall be elected annually at the last Meeting of the Session. Nominations for the various offices shall be made at the meeting previous to that at which the election is to take place; and a list of such nominations, and the names of the proposers and seconders, shall be sent to each Member of the Society at least seven days before the date of election. The newly-elected Council and Officers shall take office on the first Wednesday in November, up to which date the old Council and Officers shall continue in office. Any vacancies occurring during the year shall be filled up by the Council.

RULE VI.

Auditors.

The Treasurer's Annual Statement of the funds of the Society, and of the receipts and payments during the past year, terminating on December 31st, shall, after being duly audited by two Members who are not on the Council, proposed, seconded, and elected at the Meeting previous to the last of the Session, be presented to the Members with the Report at the Annual General Meeting.

RULE VII.

Session and Meetings.

The Session of the Society shall commence annually on the first Wednesday in November, and terminate on the last Wednesday in April.

The Ordinary Meetings of the Society shall be held every alternate Wednesday evening at Eight o'clock, from November to April, inclusive. The Meetings shall be limited to an hour and a half's duration, but in the event of the proceedings not being completed in the hour and a half, the time may be extended, or the discussion adjourned by a vote of the Meeting.

The order of proceeding at each Meeting shall be:—

1.—The Minutes of the previous Meeting, after having been read and confirmed, shall be signed by the Chairman.
2.—Business arising out of the Minutes.
3.—Communications from the Council.
4.—Candidates for election to be announced.
5.—Candidates for election to be balloted for.
6.—Any individual present for the first time since his election, having paid the usual contributions, and signed the Register, to be introduced by the Chairman to the Meeting.
7.—Original communications to be read and discussed.

The Annual General Meeting shall be held on the last Wednesday in April, to receive the Treasurer's Statement and the Annual Report, also to elect Officers and Council for the ensuing year.

RULE VIII.

Special Meetings.

The Council may at any time call a Special Meeting, and it shall at all times be bound to do so on the receipt of a requisition signed by not less than ten Members, stating the purpose for which the Meeting is to be convened. In either case, at least seven days' notice of the time appointed by the Council for such Meeting shall be given to every Member; and the Meeting shall be held within twenty-one days after the receipt of the requisition. The notice shall specify the nature of the business to be transacted, and no other than that business shall be transacted at that Meeting.

RULE IX.

All votes on any question brought before the Society shall be given in person; those for the election of the Officers and new Members or Associates by ballot; on all other questions openly. Voting.

In the event of equality, the Chairman shall have a second or casting vote.

RULE X.

The Manuscript of the Papers read, or clear and legible copies thereof, shall become the property of the Society. Manuscript of Papers.

RULE XI.

Any Member, Associate, or Student not complying with the Rules of the Society, or guilty of misconduct, may be requested by the Council to send in his resignation to the Secretary. But if he fail to do so, the Council shall bring his case before a General Meeting, which shall deal with it as may be deemed expedient. Expulsion from the Society.

RULE XII.

Visitors may be admitted to an Ordinary Meeting, on the introduction of a Member or Associate, who shall enter their names in the Attendance Book, provided, however, that no person qualified to become a Member or Associate be admitted as a Visitor more than twice in the same year. Visitors

RULE XIII.

No addition to or change in these Rules shall be made except by a majority of not less than two-thirds of the Members present at a Special Meeting to be convened for that purpose. Addition to, or Alteration in Rules.

LIVERPOOL ENGINEERING SOCIETY.

HONORARY MEMBERS.

DATE OF ELECTION.	NAME.	ADDRESS.
24th Apl., 1895	Baker, Sir Benjamin, K.C.M.G., LL.D., F.R.S., M.Inst.C.E.	2, Queen Square Place, Westminster
31st Mar., 1897	Barry, Sir John Wolfe K.C.B., F.R.S., M. Inst. C.E.	23, Delahay Street, Westminster, London, S.W.
2nd Mar., 1898	Beresford, Rt. Hon. Lord Charles, C.B., M.P.	2, Lower Berkeley Street, Portman Square, London, W.
8th Jan., 1896	Derby, Right Hon. The Earl of, K.G., G.C.B.	Knowsley, near Liverpool
31st Mar., 1897	Fox, Sir Douglas, M. Inst. C.E.	28, Victoria Street, Westminster, London, S.W.
24th Apl., 1895	Kelvin, Right Hon. Lord, LL.D., F.R.S.	The University, Glasgow
2. 8th Nov., 1882	Lodge, Oliver Joseph, D. Sc., F.R.S.	University College, Liverpool
8th Jan., 1896	Preece, W. H., C.B., F.R.S.	Chief Engineer's Office, General Post Office, London
2nd Feb., 1881	Reynolds, Osborne, M.A., F.R.S.,	Owens' College, Manchester
2nd Mar., 1898	White, Sir William H., K.C.B., LL.D., F.R.S.	The Admiralty, Whitehall, London, S.W.

NOTE.—Figures prefixed to a name indicate the number of papers contributed and published in the yearly "Transactions."

W. prefixed to a name indicates the award of a "West Premium."

MEMBERS.

DATE OF ELECTION.	NAME.	ADDRESS.
19th Oct., 1887	Adamson, Alexander	41, Fell Street, Holt Road, L'pool
17th Feb., 1897	Adamson, John	152, Bedford Road, Bootle
2nd Mar., 1898	Aitchison, G. C.	Snowdon Mountain Railway, Llanberis, North Wales
8th Nov., 1893	Alexander, John T.	City Engineer's Office, Dale Street, Liverpool
19th Feb., 1896	Allen, Cecil A.	White Star Works, Bootle
19th Feb., 1896	Allen, Edward, M. I. Gas E.	Engineer's Office, L'pool United Gas Co., Duke Street, Liverpool
26th Nov., 1890	Aman, Frederick T., Assoc. M. Inst. C.E.	Engineer's Office, Dock Yard, Liverpool
1. 7th Nov., 1894	Anderson, John W., Assoc. M. Inst. C.E., M. I. Mech. E.	Engineering Laboratories, University College, Liverpool
13th Nov., 1895	Armistead, Reginald	c/o Chris. Geddes, Esq., 2A, Drury Lane, Liverpool
23rd Dec., 1891	Armour, James G., Stud. Inst. C.E., M. I. Mech. E.	Cereal Court A, Brunswick Street, Liverpool.
1. 13th Nov., 1895	**Aspinall, John A. F.,** M. Inst. C.E., M. I. Mech. E., M.I. and S. Inst. *Vice-President. Life Member.*	L. & Y. Railway Co., Horwich
17th Nov., 1897	Aston, Ernest William	Union Place, Oswestry
27th Nov., 1895	Aston, William	Engineer's Office, Cambrian Railway Co., Oswestry
13th Nov., 1889	Atherton, John J.	11, Folly Lane, Warrington
25th Nov., 1896	Aveyard, George S.	
11th Nov., 1896	Badger, Fred. E. G.	City Engineer's Office, Liverpool
26th Nov., 1890	Baird, Andrew H.	22, Dutton Street, Liverpool
3. 28th Nov., 1888	Bannister, M. C., Assoc. M. Inst. C.E.	Central Buildings, North John Street, Liverpool
11th Jan., 1893	Barclay, George	c/o Messrs. J. Glynn & Son, 20, Water Street, Liverpool
1. 13th Nov., 1895	Barham, H. G. Foster, Assoc. M. Inst. C.E.	Belloyanne Lodge, Jersey
20th Dec., 1893	Barker, Eric G., M. I. Mech. E.	Guyse House, Cearns Road, Oxton, Birkenhead
2. W. 12th Dec., 1888	Barling, Ivan C.	Engineer's Office, Aire and Calder Navigation Company, Goole
7th Nov., 1894	Barnes, J. E. Lloyd, Wh. Sc., M.I. Mech. E.	26, Castle Street, Liverpool

	DATE OF ELECTION.	NAME.	ADDRESS.
	2nd Nov., 1887	Barton, A., Assoc. M. Inst. C.E., Assoc. M.I. Mech. E.	Admiralty Works Department, 21, Craven Street, Charing Cross, London, W.C.
	31st Jan., 1894	Bayley, George R.	4, Sandheys Avenue, Waterloo, near Liverpool
	11th Nov., 1896	Beatson, David	5, Gordon Road, Seaforth
	7th Nov., 1894	Beckett, William M., Assoc. M. Inst. C.E.	2, Cooper Street, Manchester
1.	5th Nov., 1884	Bellamy, C. R., Assoc. M. Inst. C.E.	Corporation Gas Department, Hood Street, Liverpool
1.	23rd Nov. 1892	Beloe, Charles H., M. Inst. C.E.	13, Harrington Street, Liverpool
2.	13th Mar., 1878	**Bevis, R. Ratsey, Jun.** *Past President*—1884.	Birkenhead Iron Works, Birkenhead
1.	21st Nov., 1894	Bigley, Thomas M., Assoc. M. Inst. C.E.	19, Castle Street, Liverpool
	23rd Jan., 1889	Blackburn, R. N.	Blackburn & Sons, 20, North John Street, Liverpool
	11th Dec., 1895	Blair, Malcolm	Dallam Forge, Warrington
1.	19th Oct., 1887	Blair, W. N., Assoc. M. Inst. C.E.	Vestry Hall, St. Pancras Road, London, N.W.
	25th Feb., 1885	Blood, F. W.	Grafton Saw Mills, Grafton Street, Liverpool
	13th Nov., 1895	Boothroyd, H. T., R.N.R.	45, Thorndale Road, Waterloo
	4th May, 1892	Boscawen, P. N.	Engineer's Office, Dock Yard, L'p'l
1.	26th Mar., 1890	**Boulnois, H. Percy,** M. Inst. C.E., F.S.I. *Past President*—1893-94.	44, Campden House Court, Kensington, London, W.
5.	24th May, 1876	Boult, W. S., Assoc. M. Inst. C.E.	23, Redcliffe Road, London, S.W.
	8th Dec., 1875	Bovey, Henry T., M.A. Cantab., Assoc. M. Inst. C.E.	Professor of Engineering, McGill University, Montreal, Canada
	9th Nov., 1892	Bowden, F. W.	Public Offices, Grassendale, Aigburth
	23rd Jan., 1889	Bower, W. N.	7, Parsonage Road, Withington, Manchester
1.	27th Sept., 1880	**Bramall, Henry,** M. Inst. C.E. *Past President*—1883.	Pendlebury Collieries, near Manchester
	25th Jan., 1888	Brew, J. B.	32, Deane Road, Liverpool.
5.	19th Nov., 1885	Brightmore, Arthur Wm., D.Sc., M. Inst. C.E.	Burford House, Knighton, Radnorshire
	13th Feb., 1878	Brinckman, William, Assoc. M. Inst. C.E.	Dinorwic Quarries, Llanberis, Carnarvon
	8th Nov., 1893	Brodbelt, Thomas B.	6, Oxford Road, Waterloo, near Liverpool
1.	22nd Oct., 1884	**Brodie, John Alexander,** Wh. Sc., M. Inst. C.E., M. I. Mech. E. *President.*	City Engineer's Office, Dale Street, Liverpool
1. W.	9th Nov., 1892	**Brodie, William** *Member of Council*	Engineer's Office, Dock Yard, Liverpool

DATE OF ELECTION.	NAME.	ADDRESS.
7th Nov., 1894	Brown, David	Bootle Foundry, Vulcan Street, Bootle
3rd Apl., 1895	Browne, Wallis V.	36, Orrell Park, Aintree, L'pool
11th Dec., 1895	Brownridge, Charles, Assoc. M. Inst. C.E., F.G.S., F.R. Met. Soc.	Borough Surveyor, Town Hall, Birkenhead
18th Mar., 1896	Bruce, W. J. Willett, R.N.R.	White Star Works, Strand Road, Bootle
25th Nov., 1896	Brundrit, Dean J.	86, Hartington Road, Sefton Park, Liverpool
27th Apl., 1898	Bryce, David R.	74, Hartington Road, Sefton Park, Liverpool.
25th Jan., 1888	Buchanan, J. H.	Oswald Chambers, 5, Oswald Street, Glasgow
22nd Jan., 1896	Buckwell, G. W., Wh. Sc., M. I. Mech. E., M.I.N.A., M. I. Mar. E.	Board of Trade Surveyor's Office, Custom House Arcade, L'pool
2nd Mar., 1898	Bunch, Charles E.	Dallam and Bewsey Forges, Warrington
3. 14th Feb., 1883	Burton, G. L. Assoc. M.Inst. C.E.,	Ymuiden, Warren Road, Blundellsands.
27th Jan., 1892	Bush, Robert, B.A., Assoc. M. Inst. C.E.	Engineer's Office, Sandon Dock, Liverpool
12th Nov., 1890	Bushell, Edward H., M.I.N.A.	68, Orange Court, 35, Castle Street, Liverpool
5th Oct., 1887	Cadman, C. W.	9, Greenheys Road, Prince's Park, Liverpool
18th Mar., 1896	Calthrop, Everard Richard	56, Naylor Street, Liverpool
15th Jan., 1890	Capstick, R.	74, Grafton Street, Liverpool
8th Nov., 1893	Carruthers, J. W. B.	City Engineer's Office, Dale Street, Liverpool
24th Apl., 1895	Carter, Charles E.	Hilbury House, Parkgate, Cheshire
9th Mar., 1887	Carter, William	Hydraulic Eng. Co., Chester
26th Feb., 1890	Cartwright, Joshua, M. Inst. C.E.,	Borough Engineer, Bury, Lanc.
27th Nov., 1895	Caulton, Fred.	12, Hemans Street, Liverpool
13th Nov., 1895	Clarke, Edgar	Surveyor's Department, Council House, Birmingham
11th Nov., 1896	Clarke, John H.	Monkbridge Iron and Steel Works, Leeds
19th Feb , 1896	Clover, Matthew, M.I.N.A.	Rose Brae, Birkenhead
13th Nov., 1895	Collard, Alfred S.	Messrs. R. P. Houston & Co., Water Street, Liverpool
11th Nov., 1896	Collard, J. A.	Central Buildings, North John Street, Liverpool
21st Nov., 1883	Collier, H. M. H., Assoc. M. Inst. C.E.	Resident Engineer's Office, Limehouse Basin Improvement, North Metropolitan Railway, London
7th May, 1890	Collis, W. H., Assoc. M. Inst. C.E.,	4, Mulgrave Street, Liverpool
12th Jan., 1887	Comerford, Edward	Victoria Park, Wavertree
6th Apl., 1887	Cook, E.	Ingleside, Waterloo Park, Waterloo

	DATE OF ELECTION.	NAME.	ADDRESS.
1.	12th Jan., 1887	**Cooper, F. E.** *Member of Council.*	City Engineer's Office, Liverpool
	9th Nov., 1892	Cooper, Ralph	1, Chapel Walks, Preston
1.	4th Apl., 1894	Corbett, Joseph, M.S.I.	Borough Engineer, Town Hall, Salford
1.	10th Oct., 1877	Cornish, E. S. C.	Dock Yard, Coburg Dock, L'pool
1.	26th Feb., 1890	**Cottrell, S. B.**, M. Inst. C.E., M.I. Mech. E. *Past President*—1896-97.	L'pool Overhead Railway, Pacific Buildings, 31, James Street
	1st Dec., 1897	Coupe, E.	City Engineer's Office, Liverpool
	5th Feb., 1896	Crichton, Charles	Huskisson Engine Works, L'pool
	13th Nov., 1895	Critchley, W. C.	54, Corporation Road, Birkenhead
	1st April, 1896	Crouch, John P., Stud. Inst. C.E.	22, Scholes Bank Horwich, Lancs.
	11th Jan., 1893	Crowther, J. A., Assoc. M. Inst. C.E.	Borough Engineer, Town Hall, Bootle
	20th Feb., 1895	Cunningham, Brysson, B.E., Assoc. M. Inst. C.E.	35, Oakdale Road, Waterloo
	17th Nov., 1897	Daglish, Harry B., M. I. Mech. E.	Messrs. Robert Daglish & Co., St. Helens
	11th Jan., 1893	Dalrymple, Alex.	25, Rutland Avenue, Sefton Park, Liverpool.
4.	16th Mar., 1881	**Darbishire, Charles Henry**, J.P., Assoc. M. Inst. C.E. *Past President*—1888. *Member of Council. (Life Member).*	Penmaenmawr, North Wales
	11th Jan., 1893	Darby, Jas. T.	Church Street West, Bootle
	17th Nov., 1897	Davidson, J. R., Stud. Inst. C.E.,	6, Ivanhoe Road, Sefton Park, Liverpool
	13th Nov., 1895	Davies, Charles Edward	24, Esher Road, Liverpool
	9th Nov., 1892	Davies, Fred. Wm.	Water Engineer's Department, Municipal Offices, St. Peter's Churchside, Nottingham
	20th Feb., 1889	Davies, T.	Canning Dock Works, Liverpool
	11th Nov., 1896	Davies, T. W., Assoc. M. Inst. C.E., F.G.S.	41, Park Place, Cardiff
	12th Apl., 1893	Davies, William	Liverpool Corporation Waterworks, Llanforda, Oswestry
1.	25th Apl., 1877	Deacon, George F., M. Inst. C.E., M. I. Mech. E.	Victoria Mansions, 32, Victoria Street, Westminster, London, S.W.
	28th Mar., 1877	Dickson, John, Assoc. M. Inst. C.E.,	Glaisdale Ironworks, Grosmont, Yorks.
	12th Nov., 1890	Douglas, James T.	Queen B'dings, 11, Dale St., L'pool
	13th Nov., 1895	Downie, Thomas	Toxteth Engine Works, Caryl Street, Liverpool
	8th Feb., 1893	Duff, Peter	18, Radnor Place, Birkenhead
4. W.	13th Feb., 1878	**Duncanson, Thomas**, Assoc. M. Inst. C.E. *Member of Council.*	16, Deane Road, Liverpool
1.	13th Nov., 1895	Dunkerley, Stanley, M. Sc.	Professor of Applied Mechanics, Royal Naval College, Greenwich
	10th Nov., 1880	Dunscombe, Clement, M.A., M. Inst. C.E.	20, Victoria Street, Westminster, London, S.W.

DATE OF ELECTION.	NAME.	ADDRESS.
27th Jan., 1886	Edmiston, J. B., M. I. Mech. E., M.I.N.A.	Ivy Cottage, Highfield Road, Walton
29th Jan., 1890	Edwards, George	Carlton House, Putney Hill, London, S.W.
2. 25th Sept., 1878	Ellington, Edward B., M. Inst. C.E.	Palace Chambers, 9, Bridge Street, Westminster, London, S.W.
11th Nov., 1896	Ellis, Edward, M. Inst. C.E.	Great Northern Railway, Leeds
13th Mar., 1878	Evans, Frederick	Stanley Works, Portia Street, Stanley Road, Liverpool
7th Mar., 1888	Evans, L. T. G.	Plas Madoc, Hamilton Road, Sherwood Rise, Nottingham
1. 27th Jan., 1886	Evanson, F. M., Assoc. M. Inst. C.E.	African Chambers, 19, Oldhall St., Liverpool
18th Apl., 1894	Everett, Frederick C., Assoc. M. Inst. C.E.	Public Offices, Green Lane, Tuebrook, Liverpool
6. 12th Dec., 1888	**Farren, George,** J.P., M. Inst. C.E., F.R.S.S. *Past President*—1897-98.	Carnarvon, North Wales
11th Mar., 1885	Ferber, E. G., M. I. N.A.	City of Dublin Steam Packet Co., 9, Regent Road, Liverpool
22nd Apl., 1896	Fernie, James	30, Brunswick Street, Liverpool
25th Nov., 1896	Field, Henry H.	Messrs. Rylands Bros., Warrington
11th Feb., 1880	Fitz-Gibbon, Gerald, M. Inst. C.E.	The White House, Heysham, near Lancaster
17th Mar., 1897	Forrest, John	1, David Street, Park Road, L'pool
10th Oct., 1886	Fosbery, A. C. W.	Assistant Engineer, Bombay Port Trust, Bombay
1. 5th Feb., 1896	Fothergill, John Reed, M. I. N.A., M.I. Mech. E., Assoc. M. Inst. C.E.	Dock Office, West Hartlepool
13th Apl., 1898	Fowler, A. F., Assoc. M. Inst. C.E.	Ribble Navigation Offices, Preston
5th Dec., 1894	Fozzard, William C.	87, Walton Breck Road, L'pool
27th Apl., 1898	Francis, O. Francis	Kilmorey Park, Chester
21st Nov., 1894	Fraser, Robert B.	Messrs. A. & R. Brown & Co., 90, Regent Road, Liverpool
4th Mar., 1896	Fry, Charles E.	34, Examiner Buildings, Strutt Street, Manchester
25th Nov., 1896	Gaskin, Fredk. Wm.	Water Engineer's Office, Dale Street, Liverpool
8th Feb., 1893	Geddes, Chris., M. I. Mech. E.	2A, Drury Lane, Water Street, Liverpool
1. 7th Nov., 1894	Glover, James, Junr., M.A., Assoc. M. Inst. C.E.	Holly House, Lowton, Newton-le-Willows
13th Feb., 1880	Glover, W. W. S.	"Gleddingholme," Beresford Road, Birkenhead
3. 6th Oct., 1880	Goldstraw, William	City Engineer's Office, Liverpool
7th Nov., 1894	Goodier, Frederick	11, Higher Lane, Fazakerley, near Liverpool
12th Nov., 1890	Goodwin, Gilbert S., M.I.N.A.	Alexandra Buildings, 19, James Street, Liverpool

DATE OF ELECTION.	NAME.	ADDRESS.
9th Feb., 1887	Grace, Robert W., Wh. Sc., M. I. Mech. E.	Colorado Fuel and Iron Company, Pueblo, Colorado, U.S.A.
1st Dec., 1897	Grant, Allan J.	Birkenhead Ironworks, B'head
9th Dec., 1896	Grayson, J. H. F.	Messrs. H. & C. Grayson, Ltd., 179, Regent Road, Liverpool
7th May, 1890	Greaves, R. M.	Wern, Tremadoc R.S.O., N. Wales
6th Apl., 1892	Griffith, T. H.	Manor House, Hale, near Liverpool
9th Nov., 1892	Haarer, Ernest C.	Hydraulic Engineering Co., African Chambers, Old Hall Street, Liverpool
23rd Apl., 1890	Haldane, J. W. C.	30, North John Street, Liverpool
31st Mar., 1897	Hallas, George H.	Huyton, near Liverpool
12th Nov., 1890	Hall, Watkin	Surveyor to the District Council, Great Crosby
18th Mar., 1891	Hamilton, Andrew, M.I.N.A.	c/o Messrs. G. S. Goodwin, 19, James Street, Liverpool
9th Mar., 1887	Hardaker, A. E., Stud. Inst. C.E.,	411, City Road, Hulme, M'chester
11th Dec., 1895	Harris, Thomas	Surveyor's Office, Town Hall, Bootle
11th Nov., 1891	Harry, E. Wareham	Borough Engineer, Cambridge
9th Mar., 1892	Harvey, Robert F., Assoc. M. Inst. C.E.	16, Seaton Buildings, 17, Water Street, Liverpool
25th Nov., 1891	Haswell, Frederick J.	Liverpool Hydraulic Power Co., 123, Athol Street, Liverpool, N.
9th May, 1888	Hay, Arthur C., M.I.N.A.	3, Wellington Buildings, South Castle Street, Liverpool
4. 28th Oct., 1885	**Hele-Shaw, H. S.**, LL.D., Wh. Sc., M. Inst. C.E., M. I. Mech. E. *Past President*—1894-95. *Life Member.*	University College, Liverpool
13th Nov., 1895	Helliwell, Robt. B.	73, Wellington Avenue, Smithdown Road, Liverpool
22nd Jan., 1896	Hepburn, G. A.	11, Redcross Street, Liverpool
8th Nov., 1893	Hilton, Harold Cunliffe	City Surveyor's Office, Town Hall, Manchester
9th Nov., 1892	Holliday, J. N. T.	Water Engineer's Office, Liverpool
13th Nov., 1895	Holme, Arthur H., J.P., Assoc. Inst. C.E.	Delfield, Aigburth, Liverpool
3. 8th Nov., 1882	**Holmes, Arthur Bromley**, M. Inst. C.E. *Vice-President.*	36, Princes Avenue, Liverpool
3. 25th Apl., 1877	**Holt, Alfred**, M. Inst. C.E. *Past President*—1881.	1, India Buildings, Water Street, Liverpool
11th Jan., 1893	Holt, Robert, M.I. Mech. E.	Egypt
3rd Feb., 1897	Honiball, Charles R., A. M. I. Mech. E.	161, Fountains Road, Liverpool
13th Nov., 1895	Hope, Alaric, Stud. Inst. C.E.	Dock Yard, Liverpool
14th Nov., 1888	Hope, W., J.P., Assoc. Inst. C.E.,	10, Blackstock Street, Liverpool
13th Nov., 1895	Horner, Joseph W.	42, Upper Fox Street, Leicester
7th Nov., 1894	Hosking, Thomas	1, Thomas Street, Liverpool

	DATE OF ELECTION.	NAME.	ADDRESS.
1.	12th Feb., 1890	Howells, D. J.	c/o Messrs. Fawcett, Preston & Co., York Street, Liverpool
1.	10th Oct., 1877	**Hudleston, Ferdinand,** Assoc. M. Inst. C.E. *Past President*—1890-91.	Electric Traction Syndicate, 16, Gt. George Street, Westminster, S.W.
	3rd Nov., 1886	Hulme, E., Assoc. M. Inst. C.E.	20, North John Street, Liverpool
1.	13th Jan., 1886	Hurtzig, A. C., M. Inst. C.E.	2, Queen Square Place, Westminster, S.W.
	25th Nov., 1896	Jamieson, W.	City Engineer's Drawing Office, Dale Street, Liverpool
	9th Dec., 1896	Johnson, Ernest A.	52, Roxburgh Street, Walton, Liverpool
	1st May, 1889	Johnson, Joshua	1, Brompton Avenue, Sefton Park
	7th Nov., 1894	Johnson, W. B.	51, Egerton Street, Liverpool
	20th Feb., 1889	**Johnston, R. E.,** M. Inst. C.E. *Past President*—1892-93. *Life Member.*	Engineer's Office, Woodside Railway Station, Birkenhead
	13th Nov., 1895	Jones, Charles	8, Holly Grove, Seaforth
	26th Nov., 1890	Jones, Chas. Lloyd	6, Island Road, Garston
	26th Feb., 1890	Jones, I. M., Assoc. M. Inst. C.E.	City Surveyor, Town Hall, Chester
	22nd Oct., 1879	Jones, W. H., Assoc. M. Inst. C.E.	Engineer's Office, Dock Yard, Liverpool
	12th Dec., 1888	Jones, W.	90, Church Road, Walton
	24th Apl., 1895	Keay, R. D.	4, Park Row, Greenwich
	7th Nov., 1894	Keene, Trevor	
	23rd Dec., 1891	Kelly, Archie	Elsinore, Promenade, Liscard
	9th Mar., 1892	Keppie, J. Duncan	11, Gordon Road, Seaforth
	3rd Nov., 1886	Kerslake, W. E., Assoc. M.I. Mech. E.	16, Woodland Road, Cherry Lane, Walton
	16th Jan., 1878	King, William, M. Inst. C.E.	Gas Office, Duke Street, Liverpool
	3rd Nov., 1886	Kinghorn, J. G., M.I.N.A.	Tower Buildings, Water Street, Liverpool
	20th Jan., 1897	Knowles, Thomas R.	Paul Street, Warrington
	8th Nov., 1893	Knowles, William Leak	Engineer's Department, Douglas Electric Tramways Company, 1, Strathallan Crescent, Douglas, I.O.M.
	28th Mar., 1877	Laird, William, M.I.N.A.	Birkenhead Ironworks, Birk'head
	8th May, 1895	Lang, W. Veysey	Managing Director, Allsup & Co., Ltd., Shipbuilders, 26, West Cliff, Preston
	27th Apl., 1898	Larmuth Luke H.	2, Claribel Street, Liverpool
	31st Mar., 1897	Le Mesurier, Wm. Henry M. Inst. C.E.	Dock Yard, Liverpool
	9th Jan., 1887	Legg, W. A., Assoc. M. Inst. C.E.	Resident Engineer's Office, Birmingham Corporation Waterworks, Elan Valley, Rhayader
	20th Jan., 1897	Lewis, Thomas	
3.	7th June, 1876	Lyster, Anthony George, M. Inst. C.E.	Engineer's Office, Dock Yard, Liverpool

DATE OF ELECTION.	NAME.	ADDRESS.
25th Apl., 1877	Lyster, G. Fosbery, M. Inst. C.E.,	Engineer-in-chief, Mersey Docks and Harbour Board, Dock Yard, Liverpool; Plas Isaf, Ruthin, North Wales
13th Nov., 1895	Mackenzie, James, M.I.N.A.	c/o Messrs. David Rollo & Sons, Fulton Engine Works, L'pool, N.
1. 22nd Nov., 1893	Macmuldrow, W. G. P.	c/o Mrs. Cameron, Glenluce, Seapoint, Cape Town, S.A.
6. 25th Apl., 1877	**Maginnis, Arthur J.,** M.I.N.A., M. I. Mar. E. *Past President*—1895-96.	28, Chapel Street, Liverpool
7th Nov., 1894	Martin, Robert T.	Liverpool Corporation Waterworks, Rivington, Horwich
20th Feb., 1895	Martin, Timpron P., M.A.	Don Chambers, Paradise Street, Liverpool.
4th Nov., 1885	Mason, Charles, M. Inst. C.E.	75, Gwendoline Street, Liverpool
31st Mar., 1897	McConnan, Chas. Stodart	305, Edge Lane, Liverpool
27th Nov., 1895	McIvor, W. T.	215 to 221, Cleveland Street, Birkenhead
25th Jan., 1893	McKaig, Wm. Rae	11, Hargreaves Road, Sefton Park, Liverpool
6th Dec., 1893	McLaren, William, M.I.N.A.	Messrs. R. P. Houston & Co., 17, Water Street, Liverpool
22nd Mar., 1893	Millar, Thomas	78, Mitchell Street, Walker-on-Tyne
8th Nov., 1893	Miller, Henry	Borough Engineer's Office, Blackburn
2. 8th Nov., 1882	**Miller, Thomas L.,** Assoc. M. Inst. C.E., M.I.E.E., *Member of Council.*	51, Upper Parliament Street, and 7, Tower Buildings N., L'pool
8th Nov., 1893	Mills, Frank *Life Member.*	Red Hill, Beaumaris, Anglesey
4. 9th Apl., 1879	**Mills, William E.** *Past President*—1885. *Member of Council.*	49, Hamilton Square, Birkenhead
1st Dec., 1897	Molyneux, Thomas	Talybont, Cardiganshire
3. W. 14th Feb., 1877	**Morgan, Jas.,** Assoc. M. Inst. C.E., *Member of Council.*	City Engineer's Office, Liverpool
1. 7th Nov., 1894	Morison, D. B., M.I. Mech. E., M.I.N.A.	Messrs. T. Richardson & Sons, Engine Works, Hartlepool
1. 16th Oct., 1889	**Musker, Arthur,** Assoc. M. Inst. C.E., M. I. Mech. E. *Hon. Librarian.*	Dundas Street, Bootle
11th Nov., 1896	Musker, Charles, Assoc. M. Inst. C.E.	Dundas Street, Bootle
11th Nov., 1896	Neville, John U.	Oriel Chambers, Water Street, Liverpool
13th Nov., 1895	Newall, James	Messrs. J. Crosfield & Son, Warrington
22nd Nov., 1882	Newell, Thos. M., Assoc. M. Inst. C.E.	Engineer, North Eastern Railway Company, Dock Office, Hull
11th Nov., 1896	Nicholson, James N.	3N, Cook Street, Liverpool
14th Apl., 1897	Oglethorpe, W. A., M.I.N.A.	Engineer's Office, Dock Yard, Liverpool
25th Nov., 1896	Oliphant, James	3, Boundary Lane, West Derby Road, Liverpool

	DATE OF ELECTION.	NAME.	ADDRESS.
	9th Mar., 1892	Oliver, Hedley, M.I.N.A.	.....
	27th Nov., 1895	Owen, George, M. Inst. C.E.	Cambrian Railway Co., Oswestry
1.	5th Dec., 1877	**Pain, Coard S.**, Assoc. Inst. C.E., *Past President*—1886. *Hon. Treasurer.*	14, North John Street, Liverpool
1.	4th Apl., 1894	Parkin, John H., Assoc. M. Inst. C.E.	Corporation Waterworks, Fisher Tarn, Kendal
1.	28th Feb., 1877	Pilkington, O. S., Assoc. M. Inst. C.E. *Life Member.*	Bryn Cregin, Deganwy, Llandudno
	13th Nov., 1895	Pilling, S. W.	"The Hagg," Mirfield, Yorks; and Queen's Chambers, Manchester
	9th Nov., 1892	Platt, S. S., Assoc. M. Inst. C.E.,	Borough Engineer, Rochdale
	6th Mar., 1895	Pomeroy, Arthur, B.A.	134, Upper Parliament Street, Liverpool.
1.	9th Mar., 1887	Pooley, Henry, Jun.	29, Manchester Street, Liverpool
	2nd Mar., 1898	Pooley, J. S.	29, Manchester Street, Liverpool
3.	28th Feb., 1877	Potts, John J., Assoc. M. Inst. C.E.,	Stranton Works, West Hartlepool
	4th Jan., 1885	Price, John, M. Inst. C.E., F.S.I.,	City Surveyor, Council House, Birmingham
	13th Nov., 1895	Price, John H., A.R.I.B.A.	29, Balmoral Rd., Fairfield, L'pool
	16th Mar., 1881	Price, Joseph, Assoc. M. Inst. C.E., M. I. and S. I.	125, Bunhill Row, London, E.C.
1.	1st Dec., 1886	**Priest, Frank E.**, M. Inst. C.E. *Member of Council.*	13, Harrington Street, Liverpool
	3rd Mar., 1897	Pritchard, P. M.	87, Allington Street, St. Michael's, Liverpool
	11th Dec., 1889	Radley, Edward Y., B.A.	107, Bedford Street South, L'pool
	20th Oct., 1886	Rathbone, A. L., Stud. Inst. C.E., *Life Member.*	Greenbank, Liverpool
	1st Dec., 1897	Reade, M. Trelcavan	2, South John Street, Liverpool
	6th Dec., 1893	Reeves, Wilfred	Albany Buildings, 39, Victoria Street, Westminster, S.W.
	11th Nov., 1896	Retallack, Nicolls	"The Laurels," Smethwick, Birmingham
	23rd Jan., 1889	Richardson, R.	41, Admiral Street, Liverpool
	6th Apl., 1892	Roberts, R. O. Wynne	Borough Engineer, Oswestry
	7th Nov., 1894	Robinson, J. P.	Springfield Iron Works, Salford, Manchester
	24th Oct., 1894	Robinson, W. H.	Balliol Road, Bootle
1.	1st Dec., 1897	Rogers, Hugh	Engineer's Office, Dock Yard, Liverpool
	25th Nov., 1896	Roscoe, P. H.	10, Kelvin Grove, Liverpool
5.	21st June, 1876	**Ross, Alexander**, M. Inst. C.E. *Past President*—1880.	Engineer's Office, Great Northern Railway, King's Cross, London
1.W.	5th Dec., 1894	Rowland, William, Wh. Sc.	Messrs. Beyer, Peacock & Co., Ltd., Gorton Foundry, Manchester
	12th Nov., 1890	Rowlandson, C. A.	Engineer's Office, M. S. and L. Railway, London Road Station, Manchester

	DATE OF ELECTION.	NAME.	ADDRESS.
	30th Oct., 1889	Rowlandson, W.	140, Boundary Street, Liverpool
	13th Nov., 1889	Royston, Ernest R.	15, Water Street, Liverpool
	27th Sept., 1880	Rubery, John T.	Victoria Ironworks, Darlaston, Staffordshire
	9th Nov., 1892	Russell, H. F.	Vine House, Neston, Cheshire
	7th Nov., 1894	Rutherford, A., M.I.N.A.	Neptune Works, Bridge Street, Birkenhead
	30th Oct., 1889	Sadler, John M.	Maghull, near Liverpool
	25th Sept., 1878 / 17th Nov., 1897	**Salmon, Frank B.,** M. I. and S. Inst. *Past President*—1882.	African Chambers, Oldhall Street, Liverpool
	17th Nov., 1897	Salmon, Harry	Stranton Works, West Hartlepool
2.	3rd Nov., 1886	Saner, J. A.	Weaver Navigation, Northwich
1.	5th Oct., 1887	Sang, Walter	8, Brompton Avenue, Sefton Park, Liverpool
	9th Mar., 1892	Saunders, S. H.	19, Barnard Road, Oxton
1.	13th Nov., 1895	Scott, Wm. G., M. Inst. C.E.	Cheshire Lines Railway, Central Station, Liverpool
	15th Jan., 1890	Sharrock, C. W.	The Linthurst, near Bromsgrove, Worcestershire
	12th Mar., 1884	Shawcross, H. J., B.E. Queen's University, Ireland	Water Engineer's Office, Liverpool
	7th Nov., 1894	Shaw, G. Livingston	South Africa
	23rd Nov., 1892	Shubrook, Henry W. L.	c/o F. J. Pilcher, Esq., African Chambers, Old Hall Street, L'p'l
	29th Oct., 1890	Silver, E. H.	Messrs. J. C. Etchells & Co., 34, Lever Street, Piccadilly, Manchester
	28th Mar., 1883	Sinclair, John S. Assoc. M. Inst. C.E.	Surveyor's Office, Town Hall, Widnes
	7th Nov., 1894	Sloan, Robert A., Wh. Sc., M.I. Mech. E.	26, Castle Street, Liverpool
	16th Jan., 1884	Smith, Aston W.	Gadley, Buxton
1.	25th Jan., 1888	**Smith, J. Reney,** M.I. Mech. E. *Member of Council.*	39, Osborne Road, Tuebrook, L'pool
8.	10th Nov., 1875	Squire, W. W., M. Inst. C.E.	Bombay Port Trust, Engineer's Office, Bombay
	4th Nov., 1885	Stead, E. G., Assoc. R.I.B.A.	Werneth Chambers, 29, Princess Street, Manchester
	12th Jan., 1887	Stephenson, E. P., Assoc. M. Inst. C.E.	Surveyor's Office, District Council Offices, Llandudno
	9th Dec., 1896	Stewart, William	Messrs. Geo. Hepburn & Son, Redcross B'dings, Redcross St.
	6th Mar., 1895	Stott, Thomas B.	"The Laurels," New Ferry Park, New Ferry
	13th Apl., 1898	Strongitharm, H. H.	14, Cook Street, Liverpool
	11th Nov., 1896	Stroudley, Fred. W.	London, Brighton and South Coast Railway, Brighton
	18th Feb., 1891	Sumner, Thomas C.	Victoria Iron Works, Victoria Road, Liverpool

	DATE OF ELECTION.	NAME.	ADDRESS.
	23rd Nov., 1892	Sutcliffe, Fielden	York Lodge, Crosby Road South, Seaforth
3.	25th Feb., 1880	Tapscott, R. L., Assoc. M. Inst. C.E.	62, Croxteth Road, Liverpool
	26th Feb., 1890	Taylor, A. Lester	Prudential Buildings, 36, Dale Street, Liverpool
	26th Oct., 1892	Terry, Stephen H., M. Inst. C.E., M.I. Mech. E.	17, Victoria Street, Westminster, London, S.W.
	6th Mar., 1895	Thornton, Stanhope E., Assoc. M. Inst. C.E.	7, New Market Street, Wigan
	8th Mar., 1893	Tickle, John J.	Claughton Chambers, Hardshaw Street, St. Helens
	7th May, 1890	Timmins, Arthur, Assoc. M. Inst. C.E.	Argyll Lodge, Runcorn
	22nd Jan., 1896	Travers, W. H.	City Engineer's Office, Dale Street, Liverpool
1.	11th Dec., 1895	Tritton, Seymour B., M.I.N.A., M. Inst. C.E.	Messrs. Flannery & Tritton, 17, Water Street, Liverpool
4.	25th Apl., 1877	Tudsbery, J. H. T., D. Sc., M. Inst. C.E.	Institution of Civil Engineers, 25, Great George Street, Westminster, London, S.W.
	19th Feb., 1896	Turpin, James C.	Lloyd's Register of Shipping, 3, St. Nicholas Buildings, Newcastle-on-Tyne
	11th Dec., 1895	Urquhart, R. J.	Harrington Chambers, North John Street, Liverpool; 57, Barton Arcade, Manchester
	3rd Mar., 1897	Vawser, Charles	St. John's, West Kirby
	20th Oct., 1886	Vickess, Samuel, Jun.	54, Falkner Street, Liverpool
	26th Feb., 1890	Von Sobbe, F. A.	3, Belvidere Road, Liverpool
	27th Jan., 1886	Wakem, Peter H.	6, Prescot Drive, Newsham Park, Liverpool
	22nd Nov., 1893	Walker, John	
1.	3rd Nov., 1886	Ward, E. T., Assoc. M. Inst. C.E.,	Wadebrook House, Northwich
	25th Nov., 1896	Watson, R. W.	30, Devonshire Road, Liverpool
	11th Dec., 1889	Weatherilt, Arthur	Knowsley View, 24, Denton's Green Lane, St. Helens
	8th Nov., 1893	Webb, Walter H.	North Cliff, Egremont, Cheshire
3.	7th Dec., 1881	**Webster, John J.**, M. Inst. C.E. *Past President*—1887.	39, Victoria Street, Westminster, S.W.
	18th Feb., 1891	Wells, J. M.	London Hydraulic Power Co., Palace Chambers, 9, Bridge Street, Westminster, S.W.
	25th Nov., 1896	West, Charles H.	5, Castle Street, Liverpool
2.	25th Feb., 1885	**West, Henry H.**, M. Inst. C.E., M.I.N.A., M. I. Mech. E. *Past President*—1889-90. *Member of Council.*	British and Foreign Chambers, 5, Castle Street, Liverpool
	8th Nov., 1893	Westharne, Henry G.	154, Upper Parliament Street, Liverpool

NAME OF ELECTION.	NAME.	ADDRESS.
4th Mar., 1891	Whalley, Henry S.	3, Hunter Street, Chester
11th Nov., 1896	Wheeler, Percy	Oldbury Railway Carriage Company, Birmingham
1. 17th Nov., 1897	White, Joseph Walwyn	Old Public Hall, Widnes.
1. 19th Oct., 1887	**Wilcox, E. S.,** M. Inst. C.E. *Member of Council.*	57, Dacre Hill, Rock Ferry, Cheshire
14th Apl., 1897	Williams, W. H.	82, Queen's Road, Bootle
13th Nov., 1895	Williamson, James	Engineer's Offices, Cambrian Railway Co., Oswestry
24th Apl., 1878	Willink, Wilhem, Assoc. M. Inst. C.E.	35, Copthall Avenue, London Wall, London, E.C.
3rd Feb., 1897	Wilson, John	17, Lambeth Road, Kirkdale
1. 28th Jan., 1880	Window, Edmund R., Assoc. M. Inst. C.E.	33, Nursery Street, Fairfield, Liverpool
11th Jan., 1893	Woods, Arthur R. T., M. I. N. A.	c/o Messrs. Nelson & Co., Central Buildings, North John Street, Liverpool
13th Feb., 1878 / 22nd Oct., 1884	**Wood, John Thomas,** M. Inst. C.E. *Past President*—1891-92. *Member of Council.*	Halewood, near Liverpool
13th Nov., 1895	Wood, Herbert	456, New Chester Road, Rock Ferry
11th Dec., 1895	Woods, Walter F.	Highfield House, Crosby
12th Jan., 1887	Woodall, Corbet, M. Inst. C.E.	Palace Chambers, Bridge Street, Westminster, S.W.
4. 10th Nov., 1875	**Yeatman, Morgan E.,** M.A. Cantab., M. American S.C.E., *Past President*—1879.	Cliefden, Eltham, Kent
1. 24th May, 1876	Yerburgh, J. E., Assoc. Inst. C.E.	21, Queen Anne's Gate, Westminster, London, S.W.
17th Feb., 1897	Young, J. Denholm, Wh. Sc., M.I.N.A., M.I. Mar. E.	2a, Tower Chambers, Liverpool
14th Jan., 1880	Ziffer, Fredk. Henry *Life Member.*	

335 Total Number of Members

NOTE.—Figures prefixed to a name indicate the number of papers contributed and published in the yearly "Transactions."

W. prefixed to a name indicates the award of a "West Premium."

ASSOCIATES.

DATE OF ELECTION.	NAME.	ADDRESS.
6th Apl., 1892	**Annett, R. C. F.**, Assoc. Inst. C.E., *Hon. Secretary.*	Water Engineer's Dept., Dale Street, Liverpool
2nd Mar, 1898	Bremner, W. T.	197, Great Howard Street, L'pool
6th Jan., 1897	Burrows, Freeman	Bayford House, Sutton, Surrey
11th Nov., 1891	Burrows, Herbert F.	8, India Buildings, Fenwick Street, Liverpool
23rd Jan., 1895	Crawford, Reginald P.	Dee Oil Co., 4, Seaton Buildings, 17, Water Street, Liverpool
11th Nov., 1896	Cripps, R. D.	5, Burlington Road, Birkdale
10th May, 1893	Danson, F. C.	Liverpool and London Chambers, Exchange, Liverpool
11th Nov., 1896	Docker, Frank Dudley, Assoc. M. Inst. C.E.	Icknield Port Road, Birmingham
11th Nov., 1896	Docker, Ludford C.	Icknield Port Road, Birmingham
30th Mar., 1898	Gabrielson, D.	5, Chapel Walks, South Castle Street, Liverpool
30th Oct., 1895	Glover, J. H.	Bank Chambers, 60, Castle Street, Liverpool
11th Nov., 1896	Littler, Henry	The County Offices, Preston
11th Dec., 1895	Maples, Cecil E.	14, Cook Street, Liverpool
13th Nov., 1895	McClure, Wm. Lees, J.P.	Whiston, Prescot
27th Nov., 1895	Nicholson, A. C., F.G.S.	Salop House, Oswestry
17th Jan., 1894	Nowell, S.	68, Orange Court, Castle Street, Liverpool
17th Nov., 1897	Oppenheim, H. S., J.P.	St. Helens
2.W. 8th Feb., 1893	Pierce, Ernest W.	Town Clerk's Department, Municipal Offices, Liverpool
8th Nov., 1893	Shone, J. Fowler	24, Fenwick Street, Liverpool
19th Feb., 1896	Smith, Walter James	6, Denton Drive, Seabank Road, Liscard
8th Nov., 1893	Temple, John *(Life Associate)*	Warrington Wire Rope Co., 13, Goree Piazzas, Liverpool
4th Mar., 1896	Thomas, Walter W.	15, Lord Street, Liverpool
11th Nov., 1896	Walker, Frank, J.P.	29, African House, Water Street, Liverpool
11th Nov., 1896	Walker, William, J.P.	29, African House, Water Street, Liverpool
27th Nov., 1895	Wilcox, Henry G.	1, Holland Road, New Brighton
31st Jan., 1894	Worrall, Ernest, M.S.I.	Surveyor's Office, District Council, Penmaenmawr, N. Wales
10th May, 1893	Yates, John Joseph	1, Victoria Street, Liverpool
17th Mar., 1897	Young, Oswald W.	Egerton Park, Rock Ferry

28 Total Number of Associates

STUDENTS.

DATE OF ELECTION.	NAME.	ADDRESS.
14th Mar., 1894	Allen, Samuel Proctor	10, Barton House, Deansgate, Manchester
7th Nov., 1894	Cooper, R. W.	Engineer's Office, Dock Yard, Liverpool
8th Jan., 1896	Cottle, Frank	4, Upper Parliament Street, L'pool
20th Feb., 1895	Deakin, George W., Stud. Inst. C.E.	Holly Wood, Egerton Park, Rock Ferry
13th Apl., 1898	Edmondson, J.	Golborne, Newton-le-Willows
1st Dec., 1897	Ellison, Arthur R.	"Hoscote," West Kirby
7th Nov., 1894	Hanckel, Alfred W.	
4th Mar., 1896	Hargreaves John H.	Engineer's Office, Dock Yard, Liverpool
11th Dec., 1895	Hatton, Ernest	Dallam House, Dallam, Warrington
11th Nov., 1896	Hawkins, E. S.	Locomotive Offices, Cambrian Railways, Oswestry
13th Nov., 1895	Higson, Wm. T.	Coningsby, Blundellsands
7th Nov., 1894	Hoar, Henry S.	230, Upper Parliament Street, Liverpool
7th Nov., 1894	Kendall, Frank A.	Saxonhurst, Rock Ferry
7th Nov., 1894	Kenyon, George C.	"Beau Coin," Almond's Green, West Derby
22nd Nov., 1893	Lange, Norman	c/o Messrs. Wood and Brodie, 3N, Cook Street, Liverpool
22nd Nov., 1893	Master, Robert	74, Canning Street, Liverpool
11th Nov., 1896	Taylor, J. R.	Haygarth House, Chester
7th Nov., 1894	Warburton, Frederic J.	c/o Messrs. Sir W. G. Armstrong & Co., Engine Works Drawing Office, Elswick, Newcastle-on-Tyne
7th Nov., 1894	Williams, E. Lloyd	Contractor's Office, Littleton Panell, Devizes
13th Nov., 1895	Wood, William B.	c/o Messrs. Wood & Brodie, 3N, Cook Street, Liverpool

20 Total Number of Students

383 Total Number of Members, Associates and Students

George Reed & Co., Printers, 64, Stanley Street, Liverpool.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

FIRST MEETING—3RD NOVEMBER, 1897.

MR. S. B. COTTRELL, M. INST. C.E., M. I. MECH. E.,
the Retiring President,

INTRODUCED TO THE MEETING

Mr. GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,
the President-Elect,

WHO THEREUPON TOOK THE CHAIR.

INAUGURAL ADDRESS.

ON THE NECESSITY OF ACCURACY IN STATEMENT AND REASONING IN ENGINEERING AND THE SLOWNESS OF THE HUMAN INTELLECT IN GRASPING THE IDEA.

GENTLEMEN,

In taking the Presidency of this most useful and flourishing Society for its Twenty-fourth Session, my first duty is to return my best thanks to the Members for the honour they have done me in electing me to so distinguished a position. It is the very highest honour—on which so many of my predecessors have very rightly valued themselves—the members have it in their power to bestow, and in bestowing it upon one who is by no means an old member, all the greater honour is done to me, and I value it accordingly. I shall trust that the Society will not only not be injured in any way during

my term of office, but that its work and usefulness to many, and especially to the younger members, may greatly increase. At any rate, if it does not do so, it shall not be for want of anything that lies in my power to do for the benefit of the Society.

In the later years it has been growing by leaps and bounds, not merely in the number of its members, which is sufficiently remarkable under the steady care of our Honorary Secretary, but is also growing in the quality of the men who have joined it—men who have already done something worthy of the doing. I trust it will be a pleasure to them to recapitulate their labours here before us, which it will not be a less pleasure to our members to hear and discuss.

But, unfortunately, your President can lay no claim to any original or distinguished research, or to being the author of any new invention for the good of mankind. Your President is an ordinary man of business who goes with the crowd, devoid of distinguishing marks, but still a man who has some ideas of the duties of the President of such a Society as this is.

EXACTITUDE.

The first duty of any President of an exact Society must necessarily be to cultivate exactitude in everybody, especially in matters requiring careful and particular consideration at the hands of individual members, for our Society deals in exactness, in figures, in inference, and in reasoning powers. Any mistake in figures or in reasoning powers may lead the student far astray, and much more so the professional man, with larger and more valuable interests confided to him.

I remember, on one occasion, taking up a book on the stability of tall chimneys and the overturning power of the wind, showing that a round chimney offers to a gale of wind but half the resistance of a square chimney. This book said that the radial stress on the round chimney varied as the sine of the angle, and that the radial stress converted into a stress parallel with the wind would vary as the sine squared. This was taken as granted, until one day, making a further calculation, it was found all wrong. The sine and the sine squared would, it was found, give nothing like a correct result. I worked it out accordingly, and found that the instruction should have been, as the cosine of the angle to the wind, and as the cosine squared. This certainly was a serious mistake to make in such a book, and might have led a younger man far astray.

By exactitude in measurements, and especially in deduction, it must not be supposed that I mean merely stating that twice two are always four, and that three times three are nine, for everybody knows that: but what is meant is, that the results deduced from any consideration whatever shall be as near the truth as it is possible to get; for, observe, I am going to a further point bearing upon this very question, and on so-called exact results depends the doctrine of probabilities.

We shall have a paper on one phase of the subject (exact measurement in work in the field or survey work) from our old and honoured friend, Dr. Tudsbery, the Secretary of the Institution of Civil Engineers.

KEPLER AN ILLUSTRATION.

An instance may here be given of a man who strove after and laboured intensely for years, for what has been alluded to, without any hope of reward, and who did it in a somewhat cognate profession.

About 300 years ago there lived a man to whom this life offered very few attractions. It must have been a very hard and gloomy lookout for him indeed, considering his ill-health and labours. He got a very poor living by getting up those astrological almanacs which the followers of astrology in those days were so fond of, and this was his support for a considerable number of years. He at length got the magnificent sum of £18 a year awarded to him by his king, but it was never paid. He went from astrology to astronomy, in which solid and tremendous work was done by him; for he laid the foundation whereon Newton built, and it led to the discovery of the laws of gravitation, and afterwards to the theory of fluxions or the calculus. This man was Kepler, whose name is imperishably associated with the three great laws in astronomy, which no doubt are very well known to you all.

But before he launched these laws on the Universe it is recorded that he went over his endless calculations no less than sixty times to see whether he could find any error in them!

In speaking of exactness in measurements, a spherometer has been used by Sir Howard Grubb, F.R.S., the distinguished astronomical instrument maker and scientific man in Dublin. He was using a very delicate piece of apparatus for detecting errors in the curvative of a lens. This instrument is a small tripod with a further leg in the middle, controlled by a fine

screw. By the variations in the motions with which this moves over a gradual convex surface the truth of the curve can be proved, but if anywhere there be an error this little apparatus would instantly detect it, and it will discover an error of a fifty thousandth part of an inch. Sir Howard says that with special precautions an error can be observed to the limit of 150,000th part of an inch.

It is well for us sometimes to take a look round and see what other people are doing, and have done, and especially those determined perseverers against all obstacles, who are interesting to the young and rising, for they derive great encouragement therefrom. Those who have risen can complacently rest upon their oars and watch, and indeed aid the progress of any coming man, and a case to which I am going to allude is one particularly interesting to me, because it was that of an old friend to whom I owe very much indeed, but who is since dead. The career of the man which will be shortly alluded to is that of the late Edwin Clark, whose portrait can now be seen in the Institution of Civil Engineers, with Stephenson and others engaged on the Britannia Tubular Bridge. He is standing there advocating the advisability of building the tubes ashore, instead of *in situ*, floating them into position, and hoisting them up into their ultimate site by the hydraulic press, which he did so much to bring forward, and which afterwards Lord Armstrong took up.

PERSEVERANCE ATTESTED.

Edwin Clark was a very poor boy at Marlow. He ran about in a corduroy suit with brass buttons, and the whole of his wealth consisted of a pocket knife. He often told me that the very first thing that gave him a start in scientific questions was hearing an itinerant lecturer giving a lecture on electricity. He was so moved by what he saw and what he heard, that nothing would satisfy him but that he must himself have an electric machine, and do all that he had seen done.

Now think for an instant of this. A poor boy, without means and without books—for he has often said to me in relating the circumstance, that now for one shilling you can get a book giving a multitude of details on electricity, and indeed for a penny now you can go to the Victoria University in this great city and hear a lecture on that or any particular subject, and you can also, at the end of the lecture, question the lecturer upon any point you want to know.

But Edwin Clark determined to persevere. A large pickle jar formed his glass cylinder. A friend of his, a tea grocer, gave him

some lead in which they wrapped up tea, and another friend, an optician, gave him a little quicksilver from a broken weather glass. This formed his amalgam. A bit of his mother's apron formed the wrapper and the cushion. A few old nails on an insulated stand formed the receiver, and a brass button cut off his own breeches formed the conductor, and thus, with the aid of his pocket knife, he could at length do all that he had seen done by the lecturer.

He got a job in London, near a place where there were two tall chimneys close together, and he began to study the motions of the stars at night from the same window, having nothing else to do. Now, surely, to a young man engaged in such an occupation, as much respect is due as to a great astronomer, when,

"He sees a new world swim into his ken."

The first thing that he noticed was that the stars did not arrive at the same point every night at the same time. After considerable observation, he found that they came four minutes earlier regularly every night, whereon he began, by means of a little calculation, to keep all the clocks right to which he had any access. This is as good a way as there is to keep accurate time and to regulate one's clocks.

He afterwards went to Marlow, his native place, where his great mechanical genius declared itself, and, I believe, he was sent to Cambridge. He then supposed his fortune was made, and he took to school-mastering, but he soon found that this was of no good. The driving of the elements of knowledge into the heads of a number of boys was not at all the work for him, and he could not bear it: so he determined to be an Engineer.

Here was another huge jump. He had no friends, and no one to push him on. But Robert Stephenson was then employed in making the present London and North Western Railway, and he went to his office in Westminster. He asked to see him, and of course was told that he could not possibly do so, but that he must make an appointment, and state his business. This was not Edwin Clark's intention. He went there every day for a week to try and attract the attention of the great man.

He saw him on several occasions, and while waiting there for a chance of speaking to him, Stephenson came out and said, "Where is this young man that has been waiting seven days to see me?" Clark instantly knew that his time had come, and he offered to do anything for Stephenson—to sweep out his office for nothing—if he could only manage somehow or other to get into any engineering place, of what sort or kind he did not care.

Stephenson asked him if he could draw a catenary curve. Clark replied, "Certainly, I will do so at once." Stephenson took him on, and you know of his subsequent distinguished career, and how he helped Hodgkinson and Fairbairn in his experiments in the design of the Conway Bridge, and became the chief engineer, under Stephenson, of the Britannia Tubular Bridge, where he worked until the bridge was completed.

In those days the Electric Telegraph Co. was much troubled to find something that would prevent the electricity from leaking away from their wires. Stephenson, who was a Director of the Company, together with Bidder, put Clark to consider the question, and see what could be done. Clark was appointed Engineer to the Company, and considered the question, and invented those earthenware or china insulators that one now sees on all the telegraph posts.

The Company resolved to construct the Bristol line with this new invention, and they found that it succeeded perfectly. The wasteful leakage was at once stopped, and in the building in which he started there were only seven operators, though at the time he told me this there were seven hundred. There are now three thousand.

After a most distinguished career he retired, and died in 1894; but another engineer, of the London and North Western Railway Co., who is also dead, told me 30 years ago that if any man was wanted to do anything remarkable in a big way, there was only one man in England to do it, as far as he knew, and that man was Edwin Clark.

He has left behind him another gentleman who was one of his assistants, and who is now the senior Vice-President of the Institution of Civil Engineers, and one of our Honorary Members. Mr. Preece, C.B., F.R.S., is alluded to as the engineering head of the telegraphic department of this kingdom, and who has been asked to read a paper to us on any subject whatever, perfectly certain that it will be handsomely dealt with and be full of information to us.

Now, Gentlemen, it is usual for the President of such a Society as ours to take a general view of the state of engineering science in the world, but I do not propose to do this. It has been done by the Presidents of the parent Society far better than could possibly be done here and they have far greater means, and in many cases are themselves discoverers. After the present address is over, no one will care to look at it again. But there are one or two objects which have come prominently before me which had better be alluded to here.

The primary things in Engineering, as in physics, are motion and matter.

MOTION.

Let us deal with motion first, and allude to some of the means we have of getting about. You have doubtless read in Macaulay as to the horrible condition of the roads, even so recently as 200 years ago. You shall not be worried by recounting the number of miles now travelled by our railway trains, or the mileage of our fast ocean steamers, but we will allude to what is taking place in this great city in the shape of applying electricity to motion on the tram lines. It is really astonishing to find so large a city as this so far behind the age. In America, electric traction is almost universal, and in some of the continental cities they have used electricity for years. At Geneva, by the use of the rapid waters of the Rhone where it leaves the lake, they have a tremendous and complete installation of electricity, and everything that a town can want and use is done by that maid-of-all-work—electricity. The use of electricity will greatly improve this city. It is said that the Tramways and Omnibuses have no less than 1,500 horses out every day at the same time. The ammonia they generate is considerable. You are aware of it in every railway station or any place where horses mostly congregate. The introduction of electricity will remove all this, and a very useful innovation will take place, especially when it is used for cabs and for locomotion generally, as seems highly probable.

Another point, which has quite recently come under my own observation—the first time that it has ever been tried in England—and that is, the Snowdon Mountain Railway. In the Isle of Man they were a little before us, and they have a line up one of their hills. The Snowdon line is a rack railway worked by steam, but it is contemplated to use electricity as a motive power too. Its opening has been delayed a year by an accident which took place, which caused the engineers, Sir Douglas Fox and Francis Fox, to add a safety apparatus to the central rails. By the aid of this, a clip under the engine and under the carriages holds them down to the rack, and so prevents the cogwheels from mounting the rack and losing its hold thereof. It is said that in Switzerland they are adopting this safety clip, but on all the lines there upon which I have travelled there is none. I have been 17 times up Snowdon, the last time by railway, and very comfortable indeed it was. It was feared that, for the last time, this pleasure was enjoyed, but now I hope to have the

pleasure of going up Snowdon some 16 times more. It is said they are now putting a line up Mount Sinai, and one hopes even that line may be ascended.

There is a further mode of motion which has come to the front of late upon which, at the May Conference of our Institution in London, considerable attention was bestowed, that is, transport from place to place by means of canals, in any kind of boat. The boat can be moved slowly with a very small power indeed. It is worth while to reproduce here a table that I have seen as showing the relative expenditure of power on a canal, on railways, and road.

Miles per Hour.	On a Canal.	On a Level Railway.	On a Level Turnpike Road.
2½	55,500 lbs.	14,400 lbs.	1,800 lbs.
3	38,542	"	"
3½	28,316	"	"
4	21,680	"	"
5	13,875	"	"
6	9,635	"	"
7	7,080	"	"
8	5,420	"	"
9	4,282	"	"
10	3,468	"	"
13½	1,900	"	"

Now these results show that at slow speeds the traffic of given weights can be conducted far more economically on a canal than by other means; that where the velocity exceeds five miles an hour, the saving turns in favour of the railway, and at higher velocities the economy of the canal disappears, even when compared with the force required on a level turnpike road. No doubt the original cost of the canal was always a serious item. If we go back to the days when Necho made a canal from Bubastis to the Red Sea, and through which it is recorded by Herodotus he circumnavigated Africa, who clearly says what must prove the truth of the story to us: "That after

"proceeding a certain distance, that the sun, which used to rise on "one hand of the expedition, afterward rose on the other hand," to the present, or rather to recent days, when the Suez Canal was cut, we find that they were very costly indeed, not alone as regards labour, but as far as human life is concerned. In the early days—and even in the present day—the sacrifice of human life was appalling. The people in days of old were forced to work like the corvée in France, and all they received was a pittance in pay and an onion and a piece of bread. Even with modern appliances and diggers which will excavate 2000 yards a day—as Sir Leader Williams says—the labour is still very costly indeed, and only traffic that can afford to move slowly can be dealt with upon them.

Still, the sight of the Suez Canal is beautiful. On going one day from Cairo to Lake Timsah by the Overland Route through the desert, that lovely lake suddenly appeared below us a blue sea set in a surrounding glow of sand, and in it was a ship flying the English flag, a sight that brought one's heart into one's mouth, for it is not until you have been in a foreign clime and been away for some time that the flag of England bears its true value to an Englishman.

Still, to have constructed that canal and to have carried it through was the great work of De Lesseps' life, and it was worth ten years of one's life for such an object.

As closely connected with this subject, and as making a canal through the sea, we shall have a paper by Mr. A. G. Lyster, the son of our old member, who is still honoured in this room. It is only from men who have actually done these things, and who can tell us how to proceed, and what results will follow from so doing, and by the great study necessary to such works, that we can form an opinion of a certain course, and that experience must be treasured and guarded. But the sea and its currents form a very large subject, and they are necessarily liable to very sudden and violent changes.

As still connected with water there is another important point to which attention should be drawn, and one in which every individual in this room is directly concerned. The question cannot be too much discussed and talked about, or too carefully dealt with by experts.

Mr. Goschen said the other day—and possibly the wish was father to the thought—in his address of welcome to the recent Congress of Naval Architects :—"While I sympathise with all scientific progress, I "do trust that you will not light on any new discoveries which will

"consign to the catalogue of obsolete ships all those which we now "possess." No doubt, when making that remark, he had the "Turbinia" in his mind. He knew that twenty such vessels would cost as much as one heavy ironclad. He dreaded that one out of twenty such ships might be the new discovery, and one of them might, perhaps, deal a fatal blow to the ironclad and sink her at once.

But the progress of science, or scientific discovery, will not be stopped, or even arrested for the space of a flash of lightning, by any such pious wish as Mr. Goschen expressed. No doubt that the intelligent audience I am addressing have already seen and considered the various views that have been put forward on this subject. On talking quite recently to a distinguished Admiral, he said that he did not think sufficient importance was given to the fact that these torpedo destroyers can act only within reach of land, while the big men-of-war can hold the sea and can wait.

MATTER.

Motion has been thus far considered. Now only one aspect of matter, Sewage and its Disposal, shall be dealt with.

Many years ago I took a vital interest in this question, but my course through life has not led me to continue it.

It is a very serious question indeed, and the corporation of a great city of six hundred thousand inhabitants, whose affairs it is conducting, must absolutely deal with the refuse of its population, for they cannot do it themselves without setting up fearful diseases.

Unfortunately (and this will also bear on the remarks that will eventually be made) there is no authority on the subject at all, and the authorities we do possess absolutely contradict each other, as may be seen by the remarks of the Chairman of the Manchester Committee. Who can say authoritatively whether an effluent is sufficiently pure to be passed into a river, and might not that dictum be instantly controverted?

There is one small town where they are trying the new biological method by the cultivation of bacteria in coke, which is, apparently, succeeding. This system is being tried in London, in America, and elsewhere.

These bacteria multiply enormously, and it is supposed themselves consume the offensive organic compounds in the sewage.

It is astonishing that after the millions of pounds that have been spent on experiments and all sorts of disinfectants that the whole question at this day should be, unfortunately, in the condition it is; that is, a perfectly agnostic condition, a very bad condition for a great

town to be in, with all sorts of opponents to any and every step that may be taken in any direction. In fact, from the very commencement, from the old days of cesspools to the present day, the question has helplessly drifted along, at the mercy of anyone who said with a sufficiently loud voice, that he could purify the sewage.

Being in London recently, Croydon was visited, where a sewage farm has been working for years, and the effluent then goes into the river Wandle. Here are two bottles of sewage, one which had been passed over a field once, and the second when it had passed over two to three fields. This is, apparently, without smell, and Mr. Walker, the Engineer, said he had a bottle which he had kept for ten years without any smell. But about a quarter of a mile from the effluent the clearer sewage was suddenly falling down a small passage, and though there was no smell, there was a foam on the top that pure water never would have had.

There was a strong smell of sewage on approaching the farm, and sometimes it is much stronger than at others. The Corporation are going to take in more land. But there is a strong outcry against this by the unanimous voice of the district council. But after all, the death rate is now but 12 per 1000.*

The farm, of course, does not pay. It is part of the cost of dealing with the refuse of the inhabitants and this *must* be paid for. About 230 inhabitants per acre is the present estimate of the working.

Supposing Manchester could get rid of its effluent as pure as this is it would require a farm of 2500 acres; this would be years before it got into working order; and the scheme of biological working, too, would be years before it could come into play. Besides this, there is the difficulty of the chemical refuse from various works, which are absolutely fatal to every biological experiment. The disposal of the refuse is a very great question, and the erection of destructors, now largely adopted, is a great addition to the subject. It is an exceedingly hard question to be dealt with, and one in which Manchester must be wished every success. If the Corporation can effect this, it will confer a boon on humanity.

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* The death rate of Croydon,	1886—1895,	was per 1000,	14·97
"	"	1891—1895	"	15·35
"	"	1896	"	14·58
Actual deaths during a week recently			"	12·00

[It should be the healthiest town in England.]

EXACTITUDE.

No further questions as to what has been seen and observed will be alluded to, but we will now return to the subject with which this address was started—the necessity for exactitude of figures and inference. I have before now drawn attention to the slowness of advance in physical science. It is only after years of patient study by individual men, sometimes at great expense, that any advance whatever is made. I have elsewhere said that a riotous crowd in Trafalgar Square would never receive with a feeling of intense thankfulness, and universal rejoicing, any new mathematical discovery: and Mr. W. H. Mallock goes further even than this, and he says, whilst a drunken mob may perchance destroy the great Forth Bridge, erected by Sir John Fowler and Sir Benjamin Baker, it will never afford the intelligence or the skill necessary for the erection of another. These must be sought for in a very different atmosphere.

SLOWNESS OF HUMAN APPREHENSION.

The slowness, nay, I will say the startling slowness, of advance in the human mind is strongly recorded in "Whewell's Inductive Science," an admirable work, which should be studied, I think, more than it appears to be, for the book is out of print. He points out that from the time of Archimedes, about 200 years before Christ, to the time of Stevinus and Galileo, about an interval of 1800 years, not a single step in advance in physics or mechanics was made. Like Rip Van Winkle the world went to sleep on scientific matters.

Archimedes determined the principles of statics, and investigated the lever with heavy bodies balanced on a fulcrum. He arrived at conclusions which are to be found in text books at the present day, and which are now absolutely and universally accepted as correct. He also studied the principal problems in hydrostatics. The true doctrine of hydrostatics assumes the idea of pressure in all directions in a confined fluid, but it also wants a distinct idea of a fluid as a body whose parts slide over each other without friction.

In hydrostatics the most important condition of advance must be the distinct apprehension of the two ideas which distinguish statics from hydrostatics; for the ideas being once clearly comprehended, the experimental laws which they tend to express become so obvious that there can be no doubt or difficulty about them. These ideas all lie at the root of all mechanical science, and the firm possession of them is to this day the first requisite for the engineering student.

The principles having been clearly stated by Archimedes, the ideas slept, as I have already said, for many centuries. They were called up again by Stevinus, and to him is due the idea of the representation of forces by limited straight lines. He stated the triangle and the parallelogram of forces, thereby introducing geometry to statics. To Galileo are due the first principles of dynamics, the investigation of the laws of falling bodies, and the phenomena attending the pendulum.

After Galileo came Newton, with his laws of motion and his transcendental discoveries. Then followed the two Bernouillis and Descartes, with their mathematical developments showing the progress of science, but not the application of it, and so we come down to Smeaton, about the year 1760.

SMEATON'S EXEMPLIFICATION.

Your attention is now going to be drawn very strongly to the fact of the slowness of the human apprehension in dealing with all matters relating to physics and mechanics, and therefore I stop at Smeaton, who died about 130 years ago. Now Smeaton was a great engineer, and above all, a careful examiner of the phenomena of nature, but he made one great mistake. He had all these great studies before him. He had everything that Archimedes had done, everything that Stevinus and Galileo had done. He had got all Newton's discoveries, and more than all, he had got the potter's wheel, which has been in existence for some 5000 years. He had also the knife-grinder's wheel.

By the courtesy of Messrs. Stiff, of Lambeth, I was recently shown an ancient potter's wheel. I believe this firm is the only one which possesses and sometimes uses such a piece of apparatus.

About the year 1760, Smeaton was on the Council of the Royal Society of London, and this question was put before him—Whether in erecting pumps or machinery, a fly-wheel and a crank attached to them would be of any use? As the result of his studies, he condemned the crank and the fly-wheel because of the imagined difficulty due to inertia arising from arresting and starting a heavy mass at the end of each stroke. He expressed the startling opinion that the use of a fly-wheel and crank would be a greater encumbrance to a mill than would a water-wheel supplied with water pumped up by the engine.

No doubt other men might have been found who would have said precisely the reverse: but his name and his fame was so great that he may be taken as the actual spokesman of science at that time, and we now know that he was wrong.

Nature sometimes, when she is called upon, answers in very faint accents, like a whisper, as has been said before; at other times she will answer with a voice which there is no mistaking; and at other times she will not reply at all. I fancy there is no doubt that Smeaton did not appeal to Nature in this case sufficiently closely; that is to say, he did not construct for himself, notwithstanding all his great experiments and the variety of experiments that he tried, a fly-wheel and crank, and have attached to it some gear with a reciprocating motion. Had he done this, he must have given a very different answer.

Let us come on to the present time, 100 years later, and we shall find that though things are moving far faster than they did, and in some cases with enormous rapidity, such as the discovery of the Röntgen rays, there is still the same slowness of apprehension of scientific discoveries. See what has been remarked about sewage, and the present aspect of the question. But let us take the question of a water pipe and see what that tells us. Let us take a pipe nearly horizontal, and let the diameter of both ends of the pipe be exactly the same, and let there be a head of water to give motion to the water in the pipe. But this pipe shall not be of a uniform diameter all the way through. Let it gradually diminish, we will say, to a quarter of its diameter about the middle, and then become large again to its original dimension. Now let the lower end of this pipe be stopped, and let there be measuring tubes standing on the pipe, one at each end, showing the height of the head of water. So long as the current is stopped, the level of the water in the measuring tubes will be exactly the same, but when the lower end of the pipe is opened, the level of the water will descend to an hydraulic mean gradient, corresponding to the level of the pipe.

Now let us consider the speed of the water in the pipe itself. Precisely the same quantity of water comes out of the pipe that goes into it, but what about the speed of the water in the pipe itself? The water in the narrow part of the pipe must be going with 16 times the velocity that it does at both ends. What difference would this make? The original idea was that water under a considerable pressure (which is measured by its velocity) would seek any and every means

of escape—any way, whatsoever—and it was reserved to the late Professor Froude to put this one question to the test.

He put in the middle of the pipe a third measuring tube, and instead of finding the water rushing out far above the hydraulic gradient owing to its enormous velocity, as a great number of people supposed, it was found that the water stood far below the hydraulic mean level. This was his discovery, and it has only just been taken advantage of in the invention by an American of a new water meter. This was originally known about 100 years ago, but no advantage whatever was taken of it until the present time, again showing the slowness of apprehension with which these discoveries are made use of.

Let me urge here the proper grasp of the fundamental principles of mechanical science and the use of the accumulated experience of those who have gone before, as the true and only reliable weapons with which the arena of engineers must be entered.

I am aware I am addressing a critical audience. May I ask them one question? That is, as in the course of their studies they must have often had questions of an abstract kind, and having only facts to go upon, have they invariably given the correct answer? That that answer has been true to the knowledge they then possessed is undoubtedly true.

We sometimes meet a man who, boasting of his hunting, has declared that he never met with a fall: but we immediately assume that he cannot have ridden far.

Advances in engineering have always followed, and sometimes have necessitated advances in knowledge on which engineering science is based. It is natural philosophy in its widest sense. From practice in an elementary form eventually comes theory, true or false, according to completeness or incompleteness of the premises. But theory leads to great advances in practice.

A practical man, in the popular mind, is one whose intelligence is acting unclouded by reasons for his actions. He despises theory altogether. But what sort of business would a cotton broker do if he was not a theorist, as well as a practitioner and a man of the world?

There is a necessity for a true grasp of first principles, not always to be intruded in the midst of one's daily work, but like a policeman's bull's-eye, reliable in a moment for the solution of vague and difficult questions. A broken neck is much more likely in the dark than in the light.

Let me conclude, by again urging the necessity for exactness of measurement, exactness of fact, exactness of statement, exactness of reasoning, and, above all, exactness of professional behaviour.

These are, I submit, the true elements of engineering success, and for advancing that profession to which we all rejoice to belong.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

SECOND MEETING—17TH NOVEMBER, 1897.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,

PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz.—Messrs. ERNEST W. ASTON, HARRY B. DAGLISH, J. R. DAVIDSON, FRANK B. SALMON, HARRY SALMON, and J. WALWYN WHITE, as *Members;* and Mr. H. S. OPPENHEIM as an *Associate.*

ELECTRO-ZINCING.

BY SHERARD COWPER-COLES, Assoc. M. Inst. C.E., M. I. Mech. E.

AMONGST the most noteworthy changes of late years in the materials employed for constructional and engineering purposes is the very extensive substitution of steel for wrought iron. Ironmasters are dispensing with the puddler's services, and are using steel instead of puddled bars for rolling down into sheets, hoops, strips, and other products, while engineers are now employing steel in many situations where formerly only iron was to be found. The age of iron is giving place to an age of steel.

With its many advantages over iron, steel unfortunately possesses one serious drawback, it corrodes more rapidly. Let me adduce a few figures on this point :—

Mallet has found the comparative liability of iron and steel to oxidation in moist air to be :—

Cast iron = 100 ; wrought iron = 129 ; steel = 133.

Sir George Findlay, in his book, "The Working and Management of an English Railway," states that the corrosion of steel rails as compared with iron rails is in the proportion of about five to four, and that in tunnels and manufacturing districts where sulphurous and other acid gases are present in the atmosphere, the life of a steel rail is shortened to a material extent.

In connection with the presence of acid gases in the atmosphere, I may mention that Dr. Angus Smith, many years ago, found that 100 cubic feet of black smoke contained 33 grains of sulphuric acid, and further, that in London, the acidity of rain, calculated as sulphuric acid, was rather more than two grains in ten gallons, and that of Glasgow more than ten grains.

Thin steel plates are largely used for constructing the hulls of such vessels as torpedo boats, but thin steel oxidizes even more rapidly than thick steel, in consequence of the scales of rust being thrown off, as soon as formed, by the expansion and contraction from alterations of temperature.

To such an extent is the evil of the corrodibility of steel felt that some engineers still object to its use, or specify that a large portion of the work, such as the upper deck floors, &c., is to be of iron. In the face of these facts the question of an effective protective covering for steel becomes of supreme inportance.

What then is the most effective protective coating for iron and steel? At present the answer is, decidedly, zinc ; though I believe that in the near future we may expect to see aluminium coatings superseding those of zinc, although experiments in this direction have not yet met with success.

Sea air, charged as it is with brine, is more destructive in its action upon galvanized iron work than the air on land, as it forms a chloride which is readily soluble. Mr. Chas. Young, in a paper read before the Society of Arts, mentions that a zinc sheathing attached in places to an iron plate which has been submerged in the sea off Portsmouth, was found to have dissolved to the extent of one ounce per square foot in twelve months, and that zinc, to retain a clean surface, must

exfoliate or waste at about the same rate as copper, namely, two ounces per square foot per annum.

Zinc is much affected by all acids, organic and inorganic, hence zinc does not afford much protection to iron when in contact with oak. Soot forms a galvanic couple with zinc in the presence of acid and water. The action of water containing lime salts on zinc is very much the same as that of moist air, the metal becoming coated with a protective covering of mixed oxide and carbonate. Hot galvanizing is often condemned as reducing the tensile strength of iron and steel, when the fault really lies with the smith who sends the work to be galvanised when he has made a bad weld, instead of leaving it in the black for inspection.

But still, as I have said, zinc forms the most effective coating for iron at present in practical use, and I will now briefly touch on the nature of the protection that it affords. Iron coated with zinc surfaces, after a short exposure, becomes covered with a thin film of oxide, which gradually passes into a basic carbonate and adheres tenaciously, forming a protective covering to the zinc. So long, therefore, as the zinc surface remains intact the underlying iron is effectively protected from corrosive action. The nature of the protective influence of the zinc on the iron is galvanic, zinc being electro-positive to iron.

Two metals in contact in the presence of moisture form a galvanic couple, and the result of the galvanic action set up under these conditions is analagous to that which takes place in a galvanic battery, viz., the electro-negative element remains unaffected so long as the action continues, the intensity of the chemical action being governed by the relative positions of the two metals in the electro-chemical series.

This electro-chemical action is sometimes curiously shown in fagotted iron bars. After lying about for some time the bars may be found to be rusted, not uniformly, but in parallel streaks running lengthways of the rod, these streaks giving the rod the appearance of having been built up of a number of parallel plates. This is evidence that the rod was originally made from fagotted iron, and the difference in electro-chemical condition of the alternate layers has given rise to the oxidation only of the alternate positive layers. Tin and iron, and copper and iron, standing some distance apart in the series, give rise to a decided galvanic action, in which the iron, as the electro-positive metal, is corroded more rapidly if the coating is partly removed than it would be if not coated at all. For this reason copper sheathing, which was first used for vessels of the English Navy about the year 1770, is now

insulated from the iron or steel hull by wood casing. This practice, no doubt, led to the strange blunder of H.M.S. "Audacious" being cased in wood, to which insulated zinc sheets were fastened, thus rendering the zinc quite worthless as a protection to the iron. With zinc and iron the positions of copper and iron, and tin and iron, are reversed. Zinc is positive to iron, and, consequently, whatever galvanic action is set up by their contact in the presence of moisture or other excitants must have for effect the solution or corrosion of the zinc and the protection of the iron. At the present time galvanizing has assumed the proportions of a very large industry, and is rapidly increasing now that steel of small section is being extensively used for constructional purposes. As compared with tinning, however, galvanizing is a comparatively new industry, having been worked in Europe during the early part of the present century, and introduced into the United States from England. Messrs. Morewood & Rogers appear to have been the first to produce commercially galvanized corrugated sheets. In December, 1846, they took out a patent for immersing articles in a bath of molten zinc, or an alloy of lead, zinc and tin, or zinc iron alloy, the surface of the molten metal being covered with sal ammoniac or chloride of manganese. To equalise the coating they employed rollers, revolving in a flux kept at a lower temperature than the melting point of the coating metal.

The chief improvements effected in hot galvanizing since its introduction have been in the construction and arrangements of the baths, and in the mechanical appliances for reducing the weight of spelter to the superficial foot. Rolled plates thus produced are not considered to be as good as flux plates, which have an average thickness of zinc of two ounces to the superficial square foot. Messrs. Davis and Sons, of Wolverhampton, have introduced a system of wet rolling the plates after annealing and pickling, the advantages claimed being a more uniform coating of zinc with a smaller consumption of spelter.

The term "galvanized iron," by the way, applied to iron that has been passed through a bath of molten zinc is somewhat misleading, since it would seem to infer that the coating was effected by galvanic current. It is intended, however, to apply to the nature of the protective influence and not to the process. Lead also is sometimes used as a protective coating for iron, but, though lead galvanizing is almost as old an industry as zinc galvanizing, it has a very limited field, for two reasons. In the first place, it affords no better protection to iron than tin when once the coating is penetrated; and

in the second place, its toxic properties render the indiscriminate use of lead-covered articles dangerous.

The comparative inertia of lead to the chemical action of many acids has given rise to the contention that it should form as good a protection to iron as zinc, if not, indeed, a better one. But a piece of lead-coated iron or terne plate, cut from a sheet and placed in water will rust badly in the course of twenty-four hours, the water and plate being discoloured with red oxide. The use to which lead or terne plate (which contains a small percentage of tin added for the purpose of ensuring a more homogeneous coating) is principally applied, is for manufacturing boxes. Attempts have been made to introduce lead-coated sheets for roofing and general purposes, but in several instances the plates were found to have rusted even before arriving at their destination. At one time a considerable quantity of lead-coated sheets were sent to Sweden to avoid the heavy duty of 66s. a ton on zinc galvanized goods, but no market was found for the sheets, and the enterprise was eventually abandoned. An American process, patented by T. J. Clamer, in 1893, and recently brought over to England, was experimented with on a commercial scale for coating iron and steel. According to the inventor, "lead while in a molten state absorbs various "gases from its surroundings and the atmosphere, the gases thus "absorbed prevent the lead from adhering closely to the surface of "metals, and cause the small holes and blisters so frequently found in "a sheet of metal coated with lead in the usual way." The American process consists of fusing the lead to be used as the coating metal under powdered charcoal, and to every 100 pounds of lead adding, first, three ounces of sal ammoniac, secondly, half an ounce of arsenic, then one ounce of phosphorous, and lastly, half an ounce of borax or a similar flux.

About the same time as the American process was put on the market, a process, called "Dinizing," for coating articles with a lead alloy, was experimented with, the object being to render the lead electro-positive to the iron. Small quantities of sodium were mixed with the lead, ammonium chloride being used as a flux.

Lead-coated wires have never been adopted by engineers, apparently on account of the electro-chemical difficulties, although manufacturers of steel wire ropes and cables for haulage purposes have on several occasions had their attention drawn to lead as a protective and lubricating coating. Lead galvanizing does not reduce the tensile strength of wires like hot galvanizing, as is shown by the figures in Table No. I.

TABLE I.

RESULTS OF EXPERIMENTS TO DETERMINE THE TENSILE STRENGTH OF WIRE, ZINC AND LEAD GALVANIZED.

	Diameter	Area	ACTUAL BREAKING LOAD		MAXIMUM STRESS	
			Tons	Pounds	Tons per square inch	Pounds per square inch
Plain ...	0·121 in.	0·0115	1·16	2598	100·9	226,000
Hot Gal. ...	0·120 in.	0·0113	1·05	2354	92·9	208,100
Lead coated	0·120 in.	—	1·15 1·175 1·20	2634	104·0	233,000
Plain ...	0·092 in.	0·006648	1·20	1190	79·9	179,001
Hot Gal. ...	0·091 in.	0·006504	1·20	1050	72·1	161,439
Lead coated	0·091 in.	0·006504	1·20	1230	84·4	189,114

The surfaces obtained by hot and by cold galvanizing differ considerably in appearance. Hot galvanized articles are often covered with large spangles or crystals, which are obtained by adding small quantities of tin to the galvanizing bath; but this attractive appearance is gained at the cost of the durability of the protection afforded to the underlying metal, as the spangles render the coating unequal in thickness and inferior in quantity. For these reasons some of our leading engineers now specify that galvanized sheets shall be without spangle, and carry zinc to the weight of one ounce per square foot.

The zinc on electro-zinced articles has an unhealthy non-metallic look, which has created considerable prejudice against such articles when compared with the brilliancy and glitter of the spangles obtained by the hot process. The dull surface of electro-deposited zinc can, by the adjustment of the current, be developed into a mat surface, which has been found especially suitable for the coating of nails, as it increases the holding properties, whilst on the other hand hot galvanizing decreases the holding power.

To surface-harden galvanized sheets, aluminum has been added to the bath of molten zinc at the moment of dipping the iron sheets, whereby a compound surface of zinco-aluminum is formed on the articles under treatment. It has been claimed that the thin film of aluminum serves as a protective coating to the molten zinc, reducing

the formation of ashes and hard zinc to about half the amount usual where protecting covers of sal ammoniac, fat, or glycerine are used; the addition of the aluminum also enables a thinner coat of zinc to be applied. According to the patentee, metallic aluminum only enters into combination with zinc in the proportion corresponding with the atomic weights of the metals.

The zinc applied by the hot process usually contains lead, tin and iron, and it has been found that iron above 0·13 per cent. makes the zinc too brittle to be properly bent. Lead up to about 1 per cent. is harmless, but above 1½ per cent. will not dissolve, and the excess collects and forms weak spots. Arsenic, antimony, cadmium and copper also occur, but practically never in quantities sufficient to be injurious. Some zinc removed from a Siemens-Martin hot galvanized plate was found to be very brittle, breaking when attempts were made to bend it. Analysis gave the following results:—

Zinc by difference	94·02
Tin	2·20
Iron	3·78
Arsenic	Trace

The average thickness of the coating was ·015 inch.

On the other hand, zinc applied by the electro process is very pure, and it is found to resist the corroding action of a saturated solution of copper sulphate (Preece's test for post office telegraph wires) very much better than hot galvanized iron. A specimen of hot galvanized iron, having 1·48 ounces per square foot, withstood three immersions, whilst a similar piece of iron, electro-galvanized, having 1·26 ounces per square foot, withstood five immersions, as shown in Table No. II.

TABLE II.

RESULTS OF SULPHATE OF COPPER TESTS MADE ON SAMPLES OF CHARCOAL IRON, COATED WITH ZINC BY DIFFERENT PROCESSES.

PREECE'S POST OFFICE TEST.

Process used to Coat the Iron.	Grs. per Square Foot.	Ozs. per Square Foot.	No. of 1 minute dips. Samples stood without showing metallic copper.
Hot Galvanizing	648·5	1·48	3
Acid Bath Zn S 04	446·4	1·02	4
Neutral Bath Zn S 04 ...	552·64	1·26	5

From this it may be inferred that with coatings of zinc of equal thickness, the article coated by the electro process will withstand the ordinary corrosion due to atmospheric influences much better than steel coated by the hot galvanizing process, or, expressed in other words, steel coated by the electro process will have as long a life as hot galvanized steel, with less zinc than would be necessary in the case of the ordinary hot process.

The process of electro-zincing is, however, not without its difficulties. The deposits obtained from zinc sulphate solution are adhesive only when great care is exercised in the preparation of the receiving surface. After pickling, the iron should be well washed in alkali, otherwise the acid is retained in the pores of the metal and sows the seeds of decay. Other matters of moment are the slowness of electro-zincing when working with a low current density, and the difficulty experienced in coating articles of irregular shape.

Difficulty is also experienced from the want of adhesion when the zinc has obtained a thickness beyond that corresponding to one ounce of zinc per square foot. Attempts have been made to overcome this difficulty by the method employed to make silver adhere to a baser metal, namely, by quickening, that is, immersing the copper or copper alloy to be silvered in an aqueous solution of mercury. As mercury will not amalgamate with iron, an electric current has to be employed. Dr. Leeson, in 1842, patented the use of mercury for preparing metallic surfaces for electro-deposition both by simple immersion and by the electro-deposition of mercury. The application of this process to the coating of iron with zinc is found to be too costly, the mercury also has a tendency to render the zinc coating brittle.

To reduce the labour that would otherwise be necessary in zincing small articles such as bolts and nuts, successful attempts were made in 1870 to coat small articles by placing them in a revolving perforated metallic cylinder. A similar arrangement has been employed for coating steel bullet jackets with cadmium and zinc.

Even when iron work is to be painted, a thin preparatory coating of zinc may be applied with great advantage. Engineers recognise the fact that the best results are obtained when the paint is applied direct to the iron surface before it has had time to rust, as the rust prevents the intimate contact of the paint and induces chemical action which causes the paint to peel from the iron. The durability of painted iron work, therefore, largely depends upon the surface of the metal being properly cleaned and prepared. An excellent surface in this respect may be obtained at a very small cost by "zinc flashing," that is,

coating the iron or steel after pickling with a thin coat of zinc, which will resist the effects of the weather and retain a perfect surface for receiving a coat of paint until such time as it can be applied.

Having briefly pointed out the importance of galvanizing and explained the nature of the results obtained, I will now endeavour to give some idea of the actual process, more especially of electro-zincing, and a description of the plant employed.

The first care in electro-zincing is to have a properly prepared surface; all traces of grease and rust must be removed. Machined work, which is usually very greasy, should be immersed for about half an hour before pickling in a hot solution of caustic soda, about half a pound to the gallon of water. The work should then be placed in a hot pickle containing about one per cent. of commercial sulphuric acid. I have found that a considerable saving of acid can be effected by placing a false bottom in the pickling tank, so as to catch the heavier portion of scale as detached, the tray being removed after the day's work and the scale collected. The same object can be attained by placing an electro-magnet behind a lead plate, the pickling solution being caused to circulate over the plate so that the scale may be attracted to the poles of the magnet and removed from time to time. After pickling, the work should be allowed to stand as long as possible in a bath of lime water.

Sand blasting is often used instead of pickling, and for many purposes it is found to give better results, especially for cast iron work, from which it is very difficult to remove the last traces of acid. The cost of sand blasting per square foot under the most favourable conditions, including cost of labour, sand and power, is $\frac{1}{10}$th of a penny, but the actual cost varies considerably with the nature of the work. When using quartz sand of the best quality the loss is about 10 per cent. each time it is passed through the machine; the loss when using chilled iron sand is very small, the waste of the material replacing more than $\frac{9}{10}$ths of the apparent loss. The plans exhibited show a complete sand blast equipment suitable for cleansing castings, plates, &c. A plate is shown in position, ready for sand blasting, the plate being caused to travel slowly through the sand blast room, whilst the two jets of sand propelled by air, at a pressure of 10 pounds per square inch, are directed over its surface by workmen. The sand, after it has done its work, passes through an open floor grating and is caught in the hopper beneath, and at intervals allowed to return to the mixing chamber, the valves of which are regulated by levers in the sand blast room.

Hitherto the great difficulty experienced in electro-depositing zinc has been to keep the electrolyte in working order, as zinc anodes, whether cast, rolled, amalgamated, or in the form of granulated zinc, fail to keep the solution up to its normal strength. I have found the adding of zinc dust to the electrolyte to be the only practical method of accomplishing this end. The zinc dust, which contains about 97·5 per cent. of metallic zinc, is cheaper in the first cost than virgin spelter, the use of it also considerably reduces the waste of zinc, as practically the whole of it is consumed. Zinc dust, or tultz, is a greyish amorphous substance, and must not be confused with zinc oxide; it is obtained as a sublimal product in the flues of the zinc smelting furnaces. Small quantities of zinc dust are placed from time to time in the generating tanks, which are connected to the depositing vats by a system of piping, the electrolyte flowing into the bottom of the depositing tanks by gravity, the lighter liquid being drawn off over a sill at the end or in the corner of the vat. The work to be zinced is secured to dogs fitted with cross bars, which rest on copper strips attached to girders carrying the anodes. This arrangement effects a considerable economy in the first cost of the plant; it has also the advantage of allowing the electrodes to be brought much nearer together than would otherwise be the case. In the illustration shown, the baths are capable of dealing with plates 6 feet by 5 feet, the tanks having a capacity of 900 gallons. The heavier classes of work are tranferred from the vats by an overhead carrier, the lighter by a trolley running on rails.

A special feature of the electrical process is that plates of very large dimensions can be speedily zinced on one or both sides, which is a matter of some importance now that plates of great length are being put in the straight run of steamer's hulls. The frames of such craft as torpedo-boat destroyers can also be galvanized after rivetting up.

The first cost of a galvanizing plant having a capacity of 6700 gallons (30 feet by 6 feet by 7 feet) is about £600, which is but little more than that of a hot galvanizing plant having a bath capacity of only 10 feet by 4 feet by 4 feet 6 inches outside dimensions. Such a hot bath would hold 28 tons of zinc, which, at £15 a ton, amounts to £420. To keep this large quantity of zinc in a molten condition entails a heavy expenditure in fuel, the thickness of the iron bath averaging more than one inch; moreover, the iron baths are a constant source of annoyance and expense, as the iron is dissolved by the zinc, resulting in the ultimate destruction of the tank. The following table gives the output of work of various sizes of zincing plants:—

OUTPUT OF WORK OF COMBINED ZINCING AND PICKLING PLANTS OF VARIOUS SIZES.
100 HOURS PER WEEK, 5200 HOURS PER ANNUM.

Size of Plant.	Output of Work per week in square feet at 1 oz. of zinc per square foot.	Output of Work per annum in square feet at 1 oz. of zinc per square foot.	Output of Work in Tons per week, $\frac{1}{16}$-in. to $\frac{3}{8}$-in. Plate.											
			$\frac{1}{16}$-in. Plate		$\frac{1}{8}$-in. Plate		$\frac{3}{16}$-in. Plate		$\frac{1}{4}$-in. Plate		$\frac{5}{16}$-in. Plate		$\frac{3}{8}$-in. Plate	
Amperes			tons	cwts.	tons	cwts.	tons	cwts.	tons	cwts.	tons	cwts.	tons	cwts.
2,900	10,284	534,768	5	15	11	10	17	4	22	19	28	14	34	9
4,500	15,508	806,416	8	13	17	6	25	19	34	12	43	5	51	18
5,600	20,011	1,040,572	10	8	20	19	33	9	44	13	55	1	66	19
7,000	25,180	1,302,360	14	1	28	5	42	7	56	4	70	5	84	6
8,800	31,017	1,612,884	17	5	34	11	51	19	69	5	86	10	103	15
10,100	36,186	1,881,672	20	4	40	8	60	11	80	15	100	19	121	5
11,600	41,356	2,150,812	23	1	46	2	69	4	92	6	115	7	138	8
14,000	46,525	2,419,300	25	19	51	18	77	17	103	17	129	16	155	15
14,500	51,695	2,688,140	28	16	57	12	86	10	115	8	144	4	173	0

The cost of electro-zincing varies with the nature of work to be zinced; the following is an estimate of cost of zincing 20 tons of plate in a working week of 52 hours, the average thickness of plates being $\frac{5}{16}$ths of an inch, and the thickness of zinc coating one ounce per square foot:—

	£	s.	d.
Labour—piecework at 1s. per cwt.	20	0	0
Incidental expenses—15 per cent. on labour ...	4	10	0
Yard labour—10 per cent. on labour	3	0	0
Zinc—448 pounds at £17 a ton	3	8	0
Royalty	3	9	8
Electrical energy at 1d. per E.M.P.	2	18	0
Pickling at 5s. per ton	5	0	0
Rent of building at £2 per week	2	0	0
Interest on capital	2	17	8
Depreciation of plant	3	17	0
	£51	0	4

Cost per ton ... £2 11s. 0d.

Both pickling and hot galvanizing have the disadvantage of reducing the strength of wires and of distorting and rendering brittle iron and steel of small section. By exposure to the lowest working temperature of the hot galvanizing bath (which averages some 1000° F., the fusing point of zinc being 775° F.), steel wire of high breaking strain has its hardness, and consequently its ultimate tensile strength and elongational efficiency reduced by as much as from 5 per cent. to 10 per cent. by the drawing of the temper and formation of an iron zinc alloy on the surface of the steel. It is the practice, when coating steel wire, to keep the bath of molten zinc at as low a temperature as possible, and to run the wire through at a high rate of speed. But these combined causes lead to a considerable waste of zinc by reason of the rapid solidification of the metal on the comparatively cold wire, and they also conduce to the ready breaking or cracking off of the covering metal on bending or twisting, owing to the difficulty with which molten zinc of low temperature adheres to the steel except after prolonged contact. In some cases the wire on leaving the bath is wiped between asbestos rubbers, but steel thus treated is found to resist corrosion only for a short period. Many attempts have been made to electro-zinc wire, but until recently it has not been found practicable to produce a wire capable of withstanding more than one immersion in a copper sulphate

solution. Most manufacturers have ceased to galvanize the best classes of steel wire (which cost some £35 per ton), on account of the great risk there is of rendering it worthless. This is unfortunate, for corrosion is found to be very marked on the inner strands of wire rope, and the advisability of protecting the steel is unquestionable.

Electro-zincing does not reduce the tensile strength or increase the elastic fatigue of steel wire, even in wires having a tensile strength of 170 tons or more per square inch, such as are used in the manufacture of pianos. The zinc coating put on by the hot process is also uneven, and the increased weight is often a matter for consideration. The thickness of the coating can only be varied within narrow limits, the minimum weight of zinc being about $1\frac{1}{2}$ ounce per square foot, the maximum 3 ounces, excepting when the molten zinc is raised many degrees above the most economical working temperature, and the articles are removed gradually from the bath so as to give the zinc time to drain off before getting chilled, or in the case of thin sheets and wires which are capable of having some of the zinc squeezed or wiped off by rollers or other suitable mechanical means. Excess of zinc has been removed from galvanized wire by passing it through asbestos rubbers, but wire thus treated soon rusts, as it is found in practice impossible to regulate the thickness of the zinc, the result being that an iron zinc alloy is formed on the surface of the iron and no true coating of zinc. The weight of metal on galvanized sheets or terne plates is usually $\frac{3}{4}$-ounce per square foot. Wires can be coated with zinc by electro-depositing to a thickness of $\frac{3}{1000}$ of an inch, or an increased diameter of $\frac{6}{1000}$ of an inch, capable of withstanding eight one minute immersions in a saturated solution of copper sulphate. A wire $\frac{69}{1000}$ of an inch in diameter, with a total thickness of $\frac{3}{1000}$-inch of zinc applied by the electro-process, will withstand repeated bending round a bar 1 inch in diameter, without exhibiting any signs of peeling or cracking.

The plans exhibited show the general arrangement of an electro-zincing plant for wires. The vat is constructed of wood and lined with sheet lead. The wood covers are also faced with lead and are provided with counter weights so that they can be readily lifted for the purpose of cleaning the vat or inspecting the wires under treatment. The covers when in position form part of the anode making electrical contact with the ridges, and thus forming a circular lead anode around each wire. The solution is circulated rapidly through the plating vat and passed into tanks supplied with zinc dust, where it is revivified.

Contact brushes, provided with weights or springs, press upon the wires in the spaces provided between the covers, collect the electric current, and at the same time burnish the zinc deposit. The plans also show another form of burnisher suitable for brightening deposits. The coated wire is caused to pass through the agate rollers, which are mounted on carriers capable of turning on centres. The carriers are arranged to move on guides, so as to respond to any unevenness or alteration of position of the wires, the guides carrying the rollers are pressed together by rubber bands or springs to give the necessary pressure for burnishing. The plans also illustrate a swift, arranged to carry two coils of wire, so as to economise space and reduce the first cost of the plant. Each swift is provided with two drums mounted so as to turn upon a spindle, the lower drum having a flange for supporting the lower coil of wire, there being between the drums and secured to the spindle a collar provided with pins or supports for carrying the upper coil of wire. The pins or supports are made so that they can be easily removed, or turned out of the way. When the coil on the lower drum becomes exhausted, a coil from the upper drum, if unexhausted, can be allowed to descend on to the lower drum by removing the pins or supports, which can then be again inserted in the collar, and a fresh coil or coils can be placed in the upper drum.

An electrolyte from which good bright deposits can be obtained is composed of 40 ounces of zinc sulphate of 1·1770 sp. gr. (= 19 per cent. of crystallized zinc sulphate), and 5 ounces of ferrous sulphate to the gallon of water, the anodes being of lead.

Dr. Kiliani, of Munich, who was the first to recognise the importance of electro-motive force in the separation of metals, found that during the electrolysis of a solution of zinc sulphate of 1·33 sp. gr. (= 76·8 ounces $Zn\,SO_4 + 7H_2O$) the anodes and cathodes consisting of zinc plates. The evolution of gas was greatest with a weak current and ceased when on one square centimetre of electrode surface three milligrammes of zinc were precipitated per minute, that is, 25·833 grains per square foot per hour. From a 10 per cent. solution the deposit was best with a current yielding from 4 milligrammes to ·2 milligrammes per square centimetre per minute, or 3·46 to 1·78 grains per square foot per hour. From very diluted solutions the zinc was always obtained in a spongy condition, accompanied by evolution of hydrogen, with a strong current, the deposit was very firm. With a weak current, and from a one per cent. solution, oxide of zinc was also precipitated even with an electro-motive force of 17 volts, when only ·0755 milligrammes of zinc was deposited per minute on one square

centimetre of cathode surface (= ·62 grains per square foot per hour). The same authority found that 2·35 volts are necessary to decompose zinc sulphate.

Electrolytes made by adding caustic potash or soda to a suitable zinc salt have been found to be unworkable on a commercial scale, the zinc oxide formed on the surface of the anode being insoluble in caustic potash or soda.

A solution of cyanide of potassium and zinc cyanide is also impracticable, both on account of cost and the insolubility of the anode. The same remarks apply to a potassio-tartrate solution, patented in 1855 by Watts, made by dissolving 200 ounces of cyanide of potassium in 20 gallons of water, to which he added 80 ounces, by measure, of strong liquid ammonia. With this solution he filled large porous cells, and put them upright in a vessel containing the bulk of the solution. He placed strips of copper in the porous cells and large zinc anode in the outer vessel, and connected them up respectively with the negative and positive poles of a battery, and allowed the current to flow until zinc had been dissolved to the extent of 60 ounces in all, or 3 ounces to each gallon of solution. To this solution he added 80 ounces of carbonate of potash by dissolving it in portions of the solution at a time and returning the dissolved salt to the bath.

A fair coat of zinc is obtained with difficulty from solutions of zinc chloride and from the fused salt. One of the great impediments to the reduction of zinc on a commercial scale has been the tendency of the zinc, after depositing in a sound state for a short time, to come down in one of the varieties of the spongy deposits.

With regard to the best working conditions, most authorities recommend a current density of 18 to 20 amperes per square foot of cathode surface, and aqueous solutions of zinc sulphate, acetate, or chloride, ammonium chloride, or tartrate, as being the most suitable for its deposition. Herman's process has also been experimented with on a commercial scale, the chief feature being the addition of the sulphates of the alkalies or alkali earths to a weak solution of zinc sulphate. Zinc deposits obtained from hot electrolytes appear to be more porous than those obtained from cold electrolytes.

Such a plant as shown on the drawings would require a current of 3500 amperes at an E.M.F. of 7 volts. When the articles to be zinced are first placed in the bath it is found advantageous to use as high a current density as possible, and after a few minutes to reduce it to about 10 amperes per square foot.

TABLE OF WEIGHTS AND THICKNESSES OF ZINC COATINGS.

Weight of Zinc, Per superficial foot	Weight of Zinc. Per superficial yard	Thickness of coating
1 oz.	9 oz.	·001698 in. or $\frac{1}{500}$ in.
$\frac{3}{4}$ oz.	$6\frac{3}{4}$ oz.	·001273 in. or $\frac{1}{600}$ in.
$\frac{1}{2}$ oz.	$4\frac{1}{2}$ oz.	·000849 in. or $\frac{1}{1000}$ in.
$\frac{1}{4}$ oz.	$2\frac{1}{2}$ oz.	·000424 in. or $\frac{1}{2000}$ in.

TABLE OF COST FOR VARIOUS THICKNESSES OF ZINC AND CADMIUM COATINGS.

Cost of Zinc per square foot	Cost of Cadmium per square foot	Weight of deposit per square foot	Thickness of deposit	
			Zinc	Cadmium
d.	d.	oz.	in.	in.
·0107	2·625	·1	·00016	·0001
·0267	6·545	·25	·0004	·00025
·053	13·125	·50	·0008	·0005
·080	19·670	·75	·0012	·0075
·107	26·25	1	·0016	·001

DISCUSSION.

Mr. J. Wemyss Anderson said—I am sure we are very much indebted to the author for such an accurate description of this process. It is not with the electrical part that I would just like to say a few words, but in connection with the actual uses of galvanized iron. In the first place, I was rather prepared to challenge the statement made by the author that hot galvanizing is often condemned wrongly for reducing the tensile strength of iron and steel. My own experience has proved that it is reduced by galvanizing, but I am at one with the author if he means it is only on small surfaces that the effect is felt, as shown by the results on wire in the author's table later on in the paper—these being so clear we can hardly challenge the first

statement, which would lead one to believe that the author thought the strength was not reduced.

In connection with coach screws, &c., we found some years ago that galvanizing made the threads more brittle and apt to break off, and consequently it was specified that the screws were to be threaded after the bar had been galvanized, with beneficial results. I would like the author's opinion on this.

Another point is the effect of the atmosphere on the galvanized surface. This is rather important, seeing the author has mentioned that the effect of soot in the presence of acid is to promote a kind of electro-chemical action which results in the plating giving way. Having just recently to deal with a condenser to be used for refrigerating purposes, I found on going into the question it was advisable to specify that the tubes should not be galvanized but coated with a special paint, the reason being that the condenser is to work on the atmospheric evaporative principle, consequently being exposed in the centre of the city. This galvanic action would be set up by the acids in the atmosphere together with any soot or carbon that might be about.

Again, experiments seemed to prove conclusively that you really get the best effect with a painted surface if the paint is well applied. Four tubes were tested: one rusted, one the ordinary plain pipe, one painted black, and one galvanized, and the result was that in experiments carried out in air, the radiation was greater in that of the black painted surface, next came the ordinary, and then the rusty surface. It appears, then, that paint can be used with advantage in such a case.

With regard to the fine coat of zinc before painting, that would of course, in most cases, be rather an expensive process, because the author has said that all surfaces must be free from grease, &c. This would mean a great deal of labour in examination and cleaning. I take it, therefore, that, generally speaking, we have yet to find a really good effective and practical method for preserving the surfaces of iron and steel on a large scale.

Mr. D. J. Howells said—I came here to-night to hear what I could upon this subject, because the Admiralty are now specifying that all boiler tubes should be electro-zinced. I see in one part of the paper it is stated that it is almost impossible to get more than one ounce per square foot to attach itself to the iron.

I would like to know whether that is proved beyond all doubt, because they specify $1\frac{1}{4}$ ounces per square foot to cover tubes.

The President, Mr. George Farren, said—One point appears in the paper to which I should like to allude. I have seen bolts taken out of a steamer marked in a very extraordinary way. The author has now accounted for this fact by explaining that this is the result of being of faggotted iron.

It seems to me that the cost of galvanizing is pretty high at present, still I hope it will eventually be brought down.

Mr. Cowper-Coles, in reply, said—With reference to Mr. Anderson's remarks, the loss in tensile strength of 5 per cent. applies to steel and iron of small section. It is hardly appreciable in sections, say, above $\frac{1}{4}$-inch. Bolts and nuts coated by both processes have been tested and it was found that in many cases a great reduction of strength took place after pickling and hot galvanizing. A thin even coating can be applied by electro-zincing to the whole of the threads without any deterioration in the quality of the metal taking place. In reply to Mr. Howell's remarks, a great number of tubes have been electro-zinced for the Admiralty having $1\frac{1}{4}$ ounces per superficial foot; for ordinary commercial purposes one ounce per superficial foot is found sufficient. Greater care has to be exercised in the preparation of the receiving surface when depositing $1\frac{1}{4}$ ounces per square foot. The estimates of the cost of the process given in the paper are very much on the safe side; in many cases where the work is similar and continuous, electro-zincing has been done as low as 30s. a ton. The figures given in the paper are for general work, such as obtains in shipbuilding yards, where the work varies so greatly; but before many years the cost will no doubt be very much reduced.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

THIRD MEETING—1st December, 1897.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,
President, in the Chair.

The following gentlemen were duly elected to the Society, viz.:—Messrs. E. Coupe, Allan J. Grant, Thomas Molyneux, M. Treleavan Reade, and Hugh Rogers, as *Members;* and Mr. Arthur R. Ellison, as a *Student.*

The two following Papers were then read.

[First Paper.]

PORTLAND CEMENT.

By PROSSER A. H. SHAW, M. Inst. C.E., Ireland.

Although Portland Cement has been very fully discussed by many leading experts on the subject during the last few years, a few practical remarks, and a reliable method of testing the quality of probably one of the greatest constructional articles in commerce may be of some little interest, and although all may not be perfectly new ground, the author trusts that the Liverpool Society of Engineers will bear with him in his few remarks which are the result of over 20 years testing and using it very extensively in large and critical structures, and which he is pleased to be able to state that so far he has never experienced a failure.

The author considers the present an opportune time for these remarks, as he believes the cement market is a matter of much moment to engineers and consumers, knowing that the price of labour, fuel, &c., has been steadily increasing in England, and the extensive competition with the foreign product of a cheap labour market, that the liability to counteract this to meet the increasing demand of the ordinary commercial consumer by adding extraneous or deleterious substances, deems it expedient that every engineer should be on the alert and have some practical idea of the article he is about to use.

It is not desirable that one should lay out plans for critical structures, taking up some books on Portland cement, adopt some views from one author and others from another, with probably his own added, and then perhaps specify a mixture that would puzzle even the best manufacturers (the author has known such instances) who often find it most difficult to meet faddists on many points. Some engineers will not have a cement unless it weighs so many pounds to the bushel, without thinking or perhaps knowing that the weight per bushel specified may militate against the grinding specified, not an uncommon occurrence, also the different methods of filling a bushel, which are very variable and often unreliable.

The following gives an example of variations, with age of an imperial bushel of cement:—

One day old weighed...	117	pounds.
One month old weighed	113	"
Two months old weighed	108	"
Twelve months old weighed... ...	103	"

So that by specifying a high weight you may get either a fresh cement or a coarsely ground one.

Fine grinding makes material alteration in weights. For instance, an imperial bushel of freshly ground cement passing through an—

80	mesh	sieve	leaving	10	per cent. residue	weighs	110 pounds.
80	"	"	20	"	"	116	"
80	"	"	25	"	"	121	"
80	"	"	35	"	"	123	"

All cement increases in bulk with age, up to the time it becomes air set, therefore the weight per bushel becomes proportionately lighter. These figures show much variation if you consider weight, which may make an important point, but which the author is inclined to absolutely neglect.

Chemical analysis has really no exact relation to the strength of cement, and as it is a very difficult operation for the general consumer,

it may, as a rule, be neglected where more crucial points can be readily arrived at to discern a sound cement, but it is very useful in detecting excess of sulphur or magnesia, which may be regarded as very dangerous adjuncts if existing in any large proportions. The following is an average composition of a sound cement :—

Lime	=	59·20
Silica	=	21·70
Alumina	=	9·82
Oxide of Iron	=	3·78
Sulphuric Acid	=	1·57
Alkalies	=	·50
Magnesia	=	·64
Moisture	=	2·79
		100·0

The author considers the necessary properties required to investigate so as to arrive at the real constructive value of Portland cement are—Fineness, Soundness, and Tensile Strain.

FINENESS.

There is little doubt that fineness is of the utmost and primary importance, and a chief factor in the ultimate strength of the concrete, and although the price may be somewhat more than of a coarsely ground cement, yet, when you consider the difference, say between a residue of 10 per cent. on a sieve of 5800 holes to the square inch, and 20 per cent. on same sieve, you pay freight, carriage, handling, &c., on 10 tons in every 100 tons, which is practically useless, being inert.

Some of the German manufacturers reach their grinding to 10 per cent. on a sieve of 32,000 holes to the square inch, but the author considers this is going to the extreme, and bordering on absurdity, as the means of testing such fineness is so difficult, and he would say uncertain. First, you should make sure of your sieve, which is not an easy task, the slightest variation in the gauge of the wire, which is naturally extremely fine, would materially affect the apertures to such an extent as to render the result valueless ; also the cement has to be worked on these sieves by means of a piece of thin brass plate, which makes it both difficult and tedious.

The author has for the past 20 years specified that not more than 10 per cent. residue by weight should be left on a 5800 mesh sieve, and considers it would be a great matter if such was adopted as a uniform

grinding; for ordinary work more sand or gravel could be used to compensate for a coarser ground cement, and it be so much less difficult for manufacturers to meet demands.

An ordinary specification is that all should pass through a sieve of 2500 meshes to square inch. When millstones alone were used for grinding this might be safe enough, as the consumer would be certain to obtain a fairly uniform and satisfactory percentage of "flour" or impalpable powder, which is an important point, but with the gradual substitution for millstones of other forms of reducing machinery and screens it is quite possible for a cement showing no residue on a 2500 mesh sieve to contain absolutely less "flour" than a cement having (say) 10 per cent. residue, but ground by a different process. A manufacturer can send out with safety in a much shorter time (after grinding) a fine than a coarsely ground cement.

Fine cement can be produced (1) by supplying the millstones by comparatively soft clinker, (2) by running the stones more slowly; (3) by bolting through a sieve and returning unground particles to the stones. The first produces an inferior cement, while the second and third add to the cost of manufacture. The author considers all these points are worthy of attention, and therefore places fineness as taken first in the order of merit.

It has been proved almost beyond doubt that the larger particles in a coarsely ground cement, by more gradual hydration, will expand and may seriously affect the internal equilibrium of the work in which such is used; beyond a certain fineness, however, it is questionable whether the consumer will get value for his money.

The following shows the variance of some specifications:—

(1)	Finely ground.					
(2)	Very finely ground.					
(3)	Extremely finely ground.					
(4)	Residue not to exceed		10	per cent. on	1600	mesh sieve.
(5)	"	"	20	"	2500	"
(6)	"	"	15	"	2500	"
(7)	"	"	10	"	2500	"
(8)	"	"	0	"	2500	"
(9)	"	"	20	"	5800	"
(10)	"	"	15	"	5800	"

The above shows the difficulty of manufacturers to meet various requirements, and tends strongly to show the advisability of a standard "fineness."

SOUNDNESS.

There are different methods of testing as to "soundness." The author has found the steaming apparatus (Faija) the most useful, ready, and satisfactory means of arriving at the soundness of Portland cement, especially when required to use immediately after delivery.

It consists of a thin copper case, the upper portion of which is filled with about quarter its depth of water; into this an inner case fits, which has two small ledges to carry pieces of plate glass on which the pats are placed about two inches from bottom; the latter is covered with water about 1½ inches deep, a graduated gas jet heats the water, and the temperature can be regulated to a nicety. Three pats are made on pieces of glass, and watched under the following conditions:—No. 1 is left in the air, No. 2 is put into water when set, and No. 3 is treated in the steaming apparatus thus:—the water is maintained at a regular temperature of 110 degrees F., the vapour filling the space being 100 degrees F.; into this vapour the No. 3 is placed for 5½ hours, after which it is immersed in the water under for about 20 hours; when this pat is taken out, if it adheres to the glass and shows no signs of blowing it may be taken as a sound cement. Blowing might possibly occur from the cement being fresh, in which case it should be spread out for a few days and treated in the bath again. If this shows the cement to be unsound by non-adherence or buckling (which the author has found in a marked degree with an inferior cement), Nos. 1 and 2 will eventually prove it, but it might be some time before these would develop the true character of the cement.

The author has been using this apparatus for over 10 years and has never found it to fail in detecting a bad cement, in fact, he has so much confidence in its efficacy that he has allowed cement which passed this test satisfactorily to be used immediately after the test.

TENSILE STRAIN

Is no doubt an important factor in testing cement, and is placed third in order of merit. There is no doubt that many users of Portland cement, if they get a good tensile strain, not unfrequently, in short periods, *i.e.*, 7 to 14 days, consider it is all right and quite safe to use. Now the author would be more inclined to doubt a cement giving a high tensile at seven days, and there is no doubt a cement can readily be supplied to give high strains at short periods if so

required, but probably with much cost in its old age, and considers it is much better to get a moderate strain at seven days (say) 350 to 400 pounds per square inch, with an increase of at least 30 per cent. at 28 days; there is little doubt that the greater the increase in strength between seven and 28 days the stronger the cement is likely to become. In 1886 he had an interesting experience; a sample of Portland cement was sent him for testing, with the following results:—On a sieve of 5800 meshes to the square inch the residue was 35 per cent., and on a sieve of 2500 meshes 18 per cent., and weighed 128 pounds per bushel. Being exceptionally heavy it was a slow setting cement, of good colour, and noted by some users as being exceptionally good, evidently being led away by merely testing for tensile strain and getting high results at short periods. Five briquettes were gauged, two of these were immersed when set and three left in the air, all were broken at end of 28 days, the two immersed giving 320 and 340 pounds, and those in the air 980, 760 and 680 pounds per square inch—averages 330 and 740 pounds. The latter would naturally appear a very good result, but considering the wide difference of those set in water and air, one of the briquettes, which gave the highest result, was immersed and observed as to its behaviour. After some time slight cracks developed and gradually spread; it was taken out of the water, when the cracks grew worse, and the whole expanded and eventually completely slaked and became an entirely disintegrated mass. This was evidently due to a preponderance of free lime, which in the early stages hardened the cement, but when total hydration occurred completely destroyed its cementatious value. This shows that free lime, as in most cements, slakes as a rule very slowly, taking sometimes as long as several months before hydration is complete on exposure to air under ordinary circumstances.

Another case, which may be of some interest, came under the author's observation last year, when he was consulted as to the cause of a serious failure in a quantity of work in cornices and window-heads in an extensive building, which was specified to be done in Portland cement, mixed with oxide of iron, as an imitation of Terra Cotta. It was premised by the architect and contractor that the cement was the cause. Having tested the cement, the author found it was perfectly sound and of a good quality, when mixed with the oxide. The briquettes were set in air, looked quite sound and gave good tensile results, one giving 740 pounds per square inch, the latter when broken was put in water, and after a short time showed signs of cracking, and when taken out of water and exposed to air, cracked all

over; this was due to a highly adulterated oxide of iron, of which the following is an analysis :—

Moisture and volatile matter...	15·54
Iron sesqui oxide	10·72
Alumina	2·55
Lime	26·01
Magnesia	0·98
$H_2 SO_4$	36·43
Alkali	1·60
Insoluble Silica	6·17
	100·0

This plainly shows the liability to err as to the real quality and judicious use of a cement, which is often condemned through ignorance, of one of the most useful articles of construction in commerce, to which so much success of some of the greatest engineering works of the period depends.

The manipulation of the machine used for testing is also a matter of some moment, notably the rate of speed in applying the stress. This is sometimes very illusory to an inexperienced manipulator, and a general rate should be adopted for comparative results.

The author adopts a speed of 100 pounds in 15 seconds. The variation of results has been proved by exhaustive experiments showing an increase of 100 pounds applied in 60 seconds is 3·9 per cent. over two minutes, and 100 pounds applied in one second is 23·1 per cent. over same.

The sand test, which is much used in Germany, suggests itself in this way to the author. Is a test made with sand, which should be perfectly uniform both in molecules and quality, a fair comparative test for arriving at the true value of Portland cement? He doubts it, and although some writers are much in favour of the sand test, he failed to find a sound reason for using it in the testing room for defining the quality of cement. Mr. Faija stated before the Institution of Civil Engineers that, "he thinks neither sand or the adhesive test likely "to supersede the generally accepted requirements of a test, and therefore "detrimental to the interests of uniform testing." On looking at a washed and sifted sand through a strong glass, all having passed through a 400 mesh sieve and retained on a 900 mesh—which is the usual grain for testing sand—it is quite apparent that the molecules are far from uniform, and a few grains of this coming into absolute contact on

a square inch section must weaken the section, not to say anything of any deleterious matter which may have escaped sieves and washing. Mr. Grant, an eminent authority, says:—"He has found two sands, "washed, passed through the same sieves and similar to each other, give "50 per cent. different results," and under these circumstances the author considers it best to arrive at the true value of the cement itself.

BURNING.

The best authorities have stated that no cement was more reliable than one which gave good results even when lightly burned, but this does not prejudice the fact that it may be improved if the same was heavily burnt. A heavy cement may denote either heavily burnt or perhaps an over-limed cement. A light colour denotes light burning, a light weight light burning, or, perhaps, an over clayed cement. A dark colour denotes a heavily burnt cement, or sometimes raw materials. A heavy weight denotes a heavily burnt or perhaps an over-limed cement. An over-limed cement has a tendency to expand, is certain at some time to blow, and is slow setting. Over-clayed cements have a tendency to contract, never acquire much strength, and are quick setting.

COMPRESSION.

Some engineers consider that we should have compressive results, as well as tensile, but it is a question if much can be said in its favour, as Portland cement will bear a greater stress, without fracture, than it can be subjected to in practice. A cubic inch of cement has been found to carry two tons, after 28 days, without fracture, and its compressive strength varies from this to as much as $3\frac{1}{2}$ tons. However, it is interesting to know the relative strength with the tensile, but when this has been arrived at it does not appear necessary to carry out regular experiments as to compression, which would be very laborious and an extremely troublesome operation to most experimenters.

The author exhibits a model concrete arch, which he made to a scale of one inch to the foot. It is of a groined form, and is one of a series of 126, each of which regularly support a load of 30 tons to the square foot, the concrete being made with one part of Portland cement to five parts of clean sharp shingle or broken stone and sand. This was designed for a malt store, holding 1,000,000 bushels of malt, for Messrs. Guinness, by Mr. W. W. Wilson, M. Inst. C.E., with

whom the author has acted as assistant for over 20 years, and who, some 18 years since, designed a similar structure without any girders whatever, which has also been a most successful piece of Portland cement concrete.

ADULTERANTS.

Of later years, admixtures such as blast furnace "slag" and "ragstone" have been used in the manufacture of Portland cement. As to the first mentioned, hard vitreous slag is almost devoid of hydraulicity, even when finely ground. The following experiment is noted by Dr. Schumann :—"Having noted that slag cement set very slowly in "12 to 20 hours, and after the initial set has taken place, the increase "in strength is much slower than with Portland cement when exposed "to the air for 14 days after having been a similar period immersed, "the difference between a slag cement and a Portland cement was "very marked; the tensile strain of the Portland being 516 pounds "per square inch, as against 182 pounds for the slag cement. When a "larger quantity of water was used in mixing, the difference was still "more marked; while the Portland cement increased 64 per cent., as "compared with an immersion period of 28 days, the slag cement lost "18 per cent. of the strength which it would have acquired if kept "under water for the whole 28 days." This is a matter of great importance, and proves conclusively the unsafeness of slag in damp foundations, and therefore, slag being a mechanical mixture of iron slag and slacked lime, is a very different constitution from Portland cement, which is a true chemical combination. It is stated by some to be equal in quality to Portland cement, but this is not admitted by the best authorities. It is noted by its high specific gravity and its colour, which is of a mauve tint in powder, and the inside of the water pat when broken is indigo. When mixed with Portland cement it may be detected thus:—To a gill of water add about 80 drops $H_2 SO_4$, drop into this 25 grains of cement, stir quickly to prevent setting, and when stirring, Condy's fluid is dropped in until the red colour remains permanent.

A genuine cement will require 10 to 15 drops, 20 as a maximum, while an adulterated cement about 30 to 60, and a cement made from slag only, probably over 200 drops. A simple test has also been formulated by Mr. Yardley, Analytical Chemist, viz.:—Place on a clean silver coin a thin layer of suspected cement, drop a small quantity of dilute $H_2 SO_4$ on it ($H_2 SO_4 + 7 H_2 O$), then rinse with

water. If cement is genuine, the treatment with acid will slightly affect the colour of the silver, but if slag is in strong proportion, a dark brown stain will be produced on the silver.

Another admixture, which more appertains to the Southern Counties, is ragstone or "Kentish Rag," which is a sandy limestone of the lower Greensand formation. It is a more or less impure carbonate of lime. The following is an analysis by Mr. Butler, F.C.S., who read a valuable paper last year, before the Society of Engineers of London, on the adulterant, which was upheld by some manufacturers :—

Insoluble silicious matter	7·28
Soluble silica	2·75
Alumina	3·70
Oxide of iron	3·34
Carbonate of lime	80·69
" magnesia	0·56
Water	1·00

Mr. Butler made exhaustive experiments with this admixture and says that "broadly speaking it does not materially affect the cement "when gauged neat, but when the adulterated cement is mixed with "sand it invariably gives lower results." The following shows the material effect when left in air and placed in sea water; cement containing 15 per cent. of ragstone when gauged with fresh water and placed in air after 12 months, shows a loss of 12½ per cent. from pure cement treated in the same way, and when mixed with sea water and placed in sea water, in 12 months shows a gain of 0·6 per cent.; the same adulterated cement, with three parts of sand added, treated in the same way, shows a loss of 48½ per cent. and 17½ per cent. respectively. It is probable that with a further quantity of sand it would be even more marked, as the inert particles of the diluent would be spread over a larger area, and therefore more injurious.

These results speak for themselves and tend to show the great danger of using Portland cement containing any diluent or extraneous admixture.

To detect "ragstone," a rough and ready method may be useful. As this adulterant is a more or less carbonate of lime, it will effervesce strongly when H C L is added; also, a briquette of "slag" cement, if immersed for 7 days and then broken, has a dark green appearance, which fades to its normal colour in a short time.

MIXING.

Having arrived at a sound Portland cement, it is a matter of much moment to treat it properly, or give it "fair play"; firstly, the aggregate should be reliable; secondly, the mixing in a dry state should be sufficient; thirdly, the water should be clean and of not too low a temperature; 50° to 60° F. if possible. The author generally requires concrete to be turned (if by manual labour) four times dry, which ensures a thorough incorporation, and three times when wetted, the water being applied through a "rose," which prevents the liability to wash the "flour" from the larger particles of the aggregate; fourthly, a sufficient quantity of water should be used, so as to ensure complete hydration, but, of course, this can be overdone for the saving of "elbow grease," and the detriment of the concrete. It should be mixed just to a good pasty composition, and it is most important that it be placed *in situ* within 20 minutes after wetting; nothing deteriorates Portland cement than working it after its initial set.

(For the Second Paper read on the evening of the 1st December, 1897, see next page.)

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

THIRD MEETING—1st December, 1897.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,

President, in the Chair.

[Second Paper.]

EXPERIMENTS IN THE ACCELERATION OF THE SETTING OF PORTLAND CEMENT.

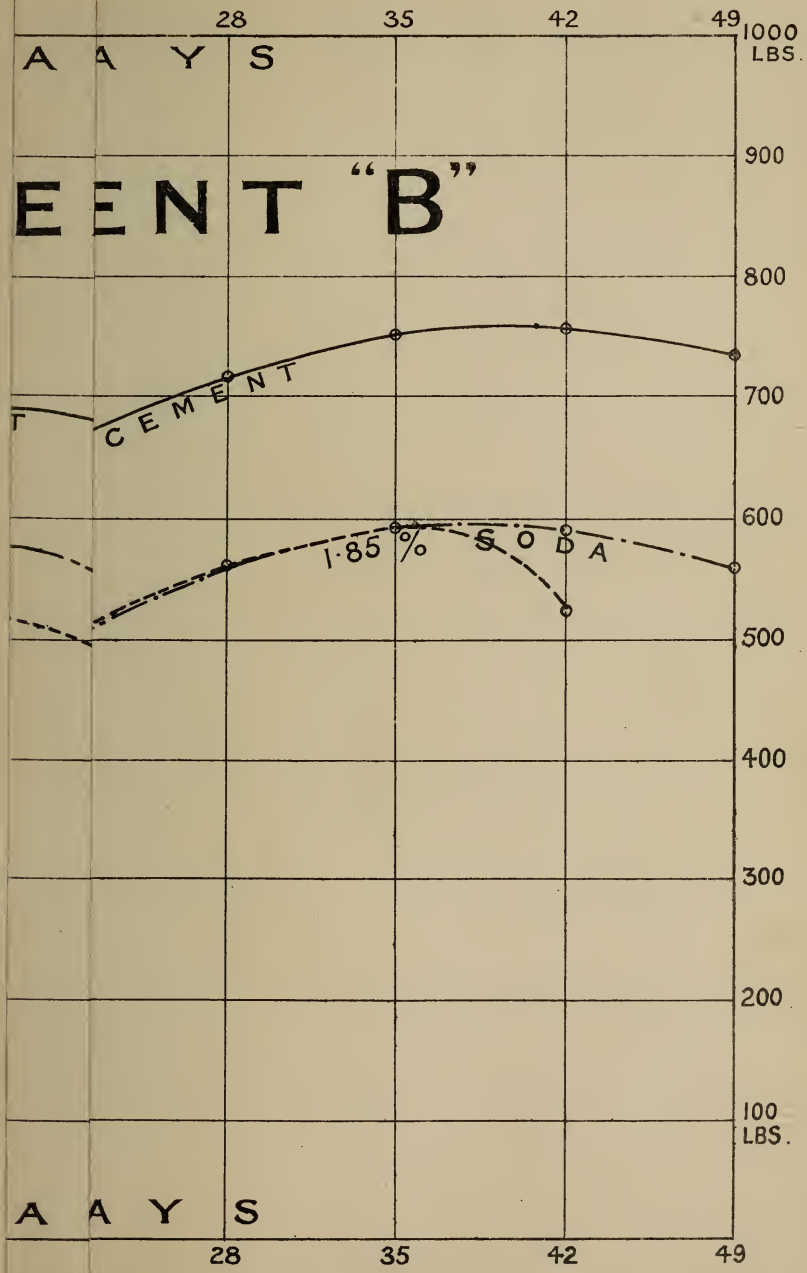
By FRANK E. PRIEST, M. Inst. C.E.

Twelve years ago Sir Frederick Bramwell said: "probably few materials "have been found more generally useful to the Civil Engineer in works "which are not of metal than has been Portland Cement." The probability then expressed will be accepted by Engineers to-day as an undoubted fact, but although Portland cement has been the subject of much research and very careful experimental investigation, I believe that there remains much to learn about it that will repay the study.

To the late Mr. John Grant, as the pioneer of the systematic examination of Portland cement in England, we owe a deep debt of gratitude, and to many gentlemen, happily still living, in this country, and in Germany, France, Austria, and Italy our thanks are due for much enlargement of our knowledge on the subject.

It has been shown that the rate of setting may be largely altered by the alteration of the proportions of the ingredients of which the cement is formed. Thus, clay in excess of the normal proportion will hasten the

PLATE I.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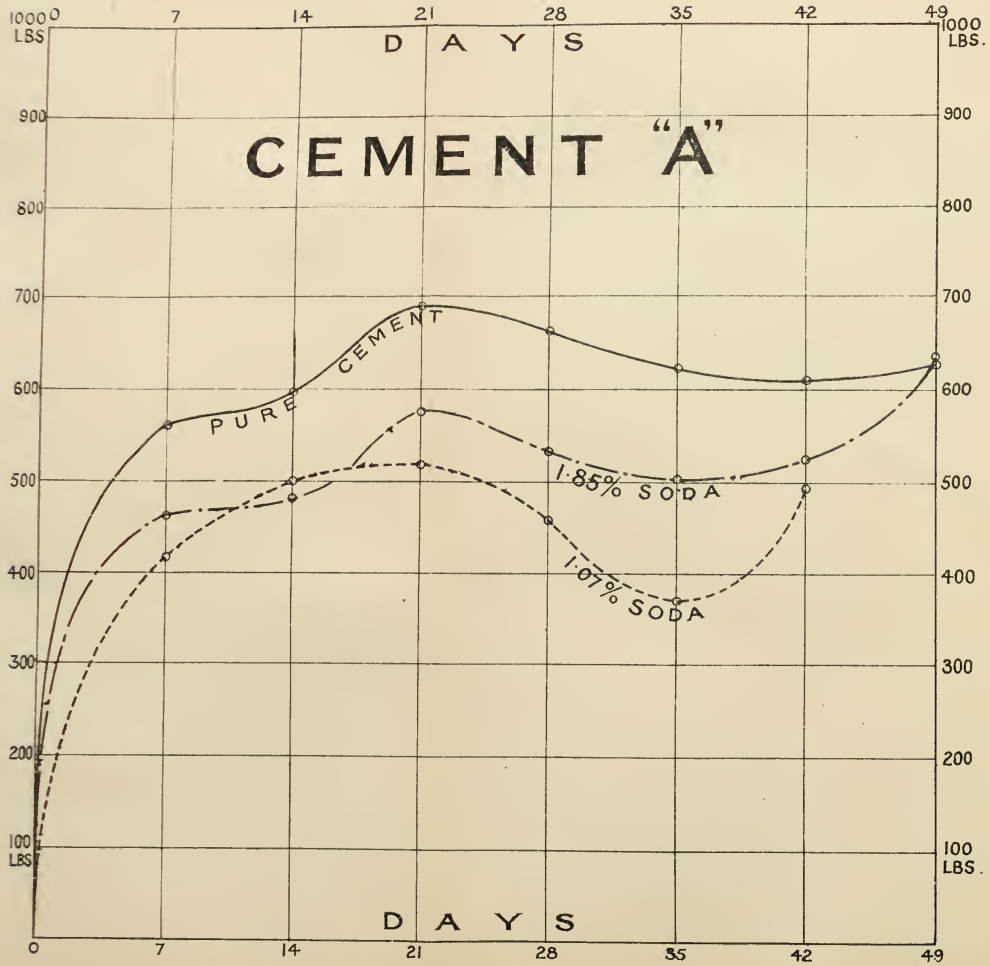

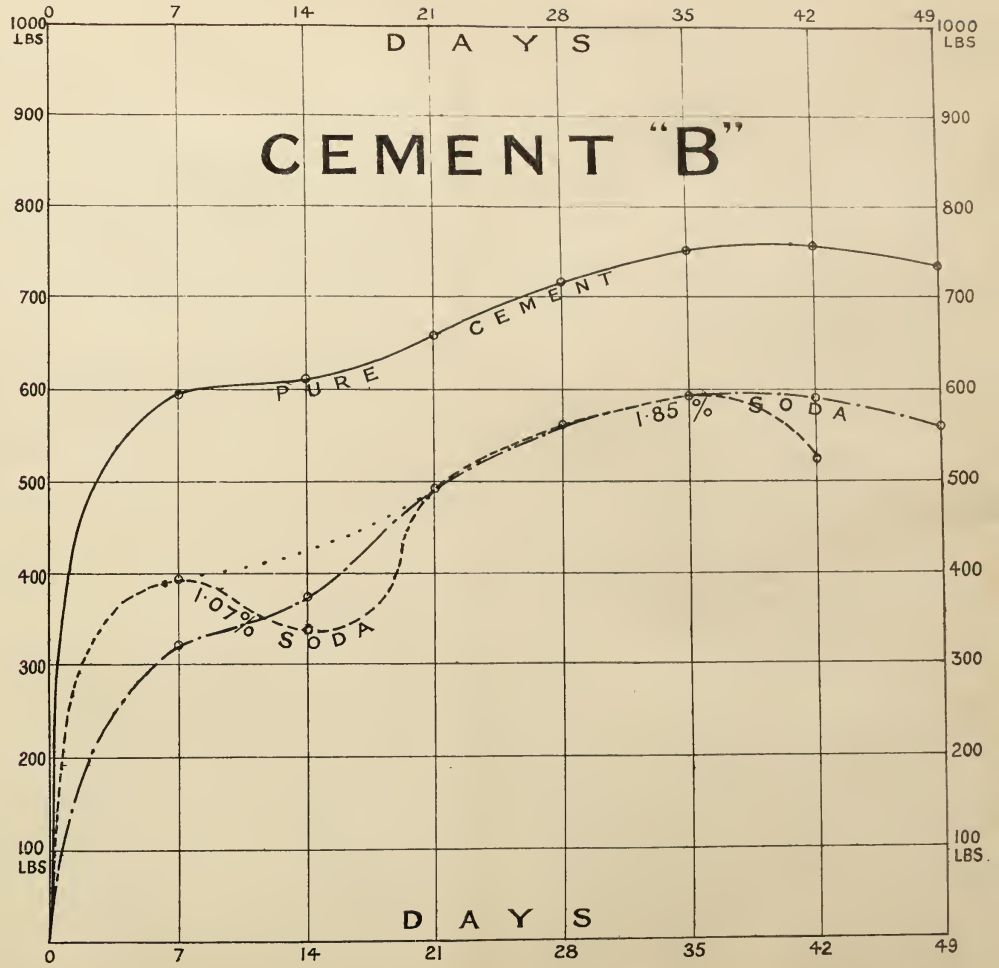

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setting, while if the lime be in excess, the setting is retarded. Sulphuric acid also retards the setting, and for this purpose Sulphate of Lime is sometimes used. It is well to notice in the case of both the methods just mentioned for producing slow setting cement the influence on the value of the cement is evil, although it produces the appearance of strength. Thus, an excess of lime renders the cement unsafe, and may eventually bring about its destruction, and with it the ruin of the structure of which it forms an important part. Sulphuric acid, while also delaying the setting, will, if present in quantities slightly greater than those usually found, reduce the ultimate strength of the cement materially.

In 1880, Signor Cantalupi pointed out that the alkalies assist in the production of good slow setting cement, and advised the addition of small quantities of carbonate of soda or potash, or common salt to the raw materials if they contain no alkali.

Much else has been written about the manufacture of cements of varying rates of setting, but the value of very quick setting cement does not appear to be recognised anywhere so well as in a paper by M. Talansier,* in which are described the several qualities of Port de France cement. Here, it is said, the quick setting quality sets in five minutes, and is used for conduits for water under pressure, and for telegraphic transmission, in drains and large culverts, and for facing and strengthening tunnels.

So far, however, in all the cases mentioned, the effect on the setting has been produced in the manufacture of the cement. It is essential in the case of large works, that the materials employed should be supplied of the exact qualities best suited to the requirements of the case, and on such works it is convenient from time to time, as the nature of the work varies, to be able to modify the character of the materials, but in small works, and in special parts of large works, and in emergencies, it is often more economical to use extravagantly the materials ready to hand than to obtain those which would be better suited, but to obtain which would involve delay, and for which a higher price would have to be paid.

Experience has taught me that two things are to be found on most engineering works, *i.e.*, Portland cement and difficulties. Experience and a sanguine temperament combined, have further induced the belief that in very many cases the one will overcome the other; whether the victory is obtained by the Portland cement or the difficulty

* Proc. Inst. C.E., lxxxiv., 455.

depends upon the treatment adopted. Of course I am referring principally to cases where water under pressure is present. In foundations, tanks and reservoirs, tunnels, conduits, culverts and sewers, and in many other classes of work, the power of readily stopping the passage of water is most valuable, and no material is more useful for the purpose than Portland cement, but with ordinary cement the time required for setting frequently renders special provision necessary for temporarily removing the water under pressure, so that the cement may be undisturbed during the process of hardening.

If, however, the rate of setting can be so accelerated as that it shall take place immediately upon putting the cement into position, the need of pumping or other means for relieving the pressure will cease.

I have not succeeded in finding much information as to ways of accomplishing this. M. Candlot, however, states that rapidity of induration and greatly increased strength may be gained by the use of a small quantity of a solution of chloride of calcium. I do not know what quantity is intended by M. Candlot, but so far I have been unable to attain any success in quickened setting by the use of calcium chloride, and conclude that the effect referred to is rather the attainment of increased strength at an early period in the age of the briquette than the shortening of the time necessary for setting.

If, however, the desired effect were obtainable by the use of chloride of calcium the peculiar characteristics of that substance would scarcely admit of its use by ordinary workmen.

In order to ascertain the effect on the rate of setting produced by various substances in common use, and therefore readily to be procured, I obtained from two makers some cement with which all the experiments which follow were made. Both makers are firms of repute, and by comparison of the tests of this cement with tests of other cement which they have delivered in the ordinary course of business to works, I am led to believe that the cement in each case was taken from the stock which they send out customarily. It will be noticed that in both cases the pure cement was quick setting. This was no doubt due to its freshness, as in both cases it was delivered soon after manufacture. For distinction the cements are called "A" and "B." The letters must not be taken as initials of the manufacturers. The time tests are taken with the Vicat needle, and in most cases both the times of beginning and of completion of setting are given, but for the present purpose it is the time of beginning of hardening only that is important.

Each cement was tested as to its time of setting when mixed with

water drawn from the Liverpool mains and also with the addition of varying proportions of common soda. Other tests were made with one or other cement with the addition of bi-carbonate of soda, sugar, common salt, sodium chloride, and glycerine. All these experiments are set forth in Table No. I. Where in the table more than one experiment is recorded of the same class it must be understood that they were made under varying climatic conditions and at different times in the age of the cements, although the whole period of the experiments was only six weeks, during which time the cement was kept close.

The percentages of the added substances are by weight in relation to the cement, and in all cases the substances were in solution in the water used for gauging. In all cases the time of setting is counted from the moment when all the cement is wet.

TABLE I.

	Setting began.		Setting completed.	
	Hrs.	Mins.	Hrs.	Mins.
Cement A, pure...	—	9·5	—	—
" with 2·48 per cent. Soda	—	1	1	40
" with 1·44 " Soda	—	0·5	1	48
" with 2·48 " Bi-Carbonate of Soda	2	5	6	51
" with 2·72 " Sugar	—	13·16	6	40
" with 2·85 " Glycerine	—	14·16	4	14
Cement B, pure...	—	8	2	18
	—	6	2	4
	—	10·5	1	40
" with 2·48 per cent. Soda	—	1·75	2	1
	—	0·75	2	38
	—	0·83	1	20
" with 1·44 " Soda	—	1	1	48
" with 0·83 " Soda	—	7·25	2	15
" with 1 " Salt	—	8	—	55
" with 1 " Calcium Chloride ...	—	20	—	—

It appears, therefore, that cement A, which, when used with pure water, begins to set in $9\frac{1}{2}$ minutes, is retarded in setting slightly by sugar and glycerine, and very greatly by bi-carbonate of soda, but that common soda reduces the time to half a minute in one case and to a minute in another.

Cement B, which, when pure, begins to set in 6 to $10\frac{1}{2}$ minutes, has its time of setting considerably retarded by calcium chloride, while common salt slightly accelerates it, this test being made under conditions corresponding to those obtaining when the pure cement took $10\frac{1}{2}$ minutes to begin to set. Common or washing soda has an effect similar to that which it has on cement A, but not quite so pronounced. In this case the setting begins after an interval of from $1\frac{3}{4}$ minutes to 1 minute, when the percentage of soda exceeds one per cent. With a lower percentage the effect is almost similar to that of common salt.

Glancing for a moment at the left hand column, it will be noticed that the times of completion of setting do not vary with those of beginning, in fact there does not appear to be any systematic relation between them.

The result of these experiments, briefly stated, is that by the addition of washing soda in the proportion of $1\frac{1}{2}$ to $2\frac{1}{2}$ per cent. by weight the time of beginning of setting of cement can be so shortened that setting will commence immediately after the mixed cement is placed in position. In this condition the cement is capable of withstanding considerable pressure. None of the other substances used have the same effect as soda, and all are useless for the purpose under consideration.

The next point to consider is the effect on the strength and durability of the cement that will be produced by the addition of soda. In ascertaining this, one is at a disadvantage which always attaches to investigations into the character of cement, namely, the necessity for great length of time for the attainment of the ultimate effects.

I regret that, for the purposes of this paper, only seven weeks have been available from the time when I was able to begin the experiments. I hope, however, to be able to continue them hereafter, and if they should disclose anything worthy of communication shall be very pleased to give the facts to any member who may desire them.

As to the presence of soda in cement, I do not know whether there is any chemical reason for anticipating an evil effect. It is present in small quantities in many, and I believe most, Portland cements. The earliest analysis of Portland cement to which I now have access, is

that of Pettenkofer and Hopfgärtner in 1849, who show soda present to the extent of 1·66 per cent. In 1880 Mr. Grant's analysis of German cements show soda varying between 0·26 and 1·7 per cent., and in English cements, soda and potash together, varying between 0·64 and 2·8 per cent. Mr. Carey gives 0·8 per cent. of soda as a usual quantity, and other analyses show percentages of soda approximating to these.

Dr. Michaëlis states that Chaux du Theil contains 0·065 and Santorin earth 4·669 per cent. of soda. These cements are found to behave quite satisfactorily in the Mediterranean, the strongly saline waters of which are destructive of Portland cement. It would therefore appear that so large a proportion as 4·669 per cent. of soda is not objectionable in a cement used for sea works.

Lastly, in Pozzuolana soda is present to the extent of 4 per cent., so that when used with lime in the proportions of 2 to 1, the resulting mortar will contain 2·66 per cent of soda.

These figures seem to indicate that the presence of soda in cement up to 4 per cent., or rather higher, is not detrimental; but I have just sufficient knowledge of chemistry to know that it is a very dangerous science for polemical purposes, especially for amateurs, and it is quite possible, I imagine, that soda present in the material of which the cement is made, may exercise a totally different influence to that which is brought upon the cement by a solution of soda used for gauging. Reference to Table No. I. will show that while washing soda has a very marked effect on the cement in one direction, bicarbonate of soda has an equally marked effect in the opposite direction, notwithstanding that the two salts are built up of the same elements in different ratios. Similarly, while according to Signor Cantalupi, the addition of common salt to the raw material assists the production of a good slow-setting cement, as previously mentioned, the addition of a solution of salt at the time of gauging has the effect of accelerating the setting (*vide* Table I.). I repeat, therefore, that although no evil influence appears to be exercised by soda in the cements in which it is found in large quantities, it would not be safe to assume that its addition to Portland cement at the time of gauging would be harmless.

The application of the pat tests to the cement used with pure water disclosed no objectionable features in the cement in either case (A and B), and equally satisfactory results with this test were obtained when soda was added. It should be remarked also that the pats were mixed with solutions of soda of the same strength as

those used for the setting tests, so that as much more water is used in the pats the percentage of soda is correspondingly higher.

The experiments made to ascertain the effect on the tensile strength of the cement by the addition of soda are given in Tables Nos. II. and III. Up to the present one hundred and fifty briquettes have been broken in the machine. They were all formed of cement neat. I thought it was advisable to exclude sand from the tests, as any effect produced by soda would be more pronounced on the neat cement than on mixed briquettes. It is probable that in most cases where very quick setting is necessary neat cement would be used.

Water was used in the proportion of 20 per cent. by weight, and the same measurement of the soda solutions was used as that of pure water. The stronger soda solution used in these experiments weighs 1·039 ozs. per fluid oz. and the weaker 1·022 oz. per fluid oz. It was found that the same measurement of the solutions and water gave as nearly as possible the same wetting effect to the cement. The briquettes were made in sets of five and the figures given are the average breaking weights per square inch per set.

TABLE II.

Tensile strength in pounds per square inch of CEMENT A *gauged with Pure Water and with Solutions of Washing Soda.*

DAYS	7	14	21	35	42	49
Cement gauged with Pure Water ...	559	598	689	622	—	625
Cement with 1·85 per cent. Soda ...	461	481	576	501	—	631
Cement with 1·07 per cent. Soda ...	416	498	518	368	494	—

TABLE III.

Tensile Strength in pounds per square inch of CEMENT B *gauged with Pure Water and with Solutions of Washing Soda.*

DAYS	7	14	21	35	42	49
Cement gauged with Pure Water ...	593	610	658	750	—	733
Cement with 1·85 per cent. Soda ...	318	373	490	589	—	558
Cement with 1·07 per cent. Soda ...	393	338	494	589	522	—

The results of the experiments given in Tables II. and III. are shown as curves on the diagrams (See Plate I.).

It will be noticed that at 7 days the briquettes which contain soda are very much lower than the pure cement ones, and if the experiments had stopped then the results would have been alarming. I believe, however, that in every case the soda briquettes have been damaged by the impossibility of completing them before setting began. It takes three minutes to work up a briquette and press it into the mould, and, as previously stated, setting begins in some cases in half a minute when soda is used.

The curves are peculiar in both cases. (See Plate I.) Those of cement A attain the greatest height at 21 days on all three lines which drop together to 35 days and then begin to rise again. The neat cement line is a little deceptive beyond 35 days, as the briquettes broken at 49 days were made by a different gauger than the others which were all made by one man. I am sure that had the set of neat cement briquettes broken at 49 days been made by the same gauger as the others they would have had considerably greater strength.

The 35 days' briquettes in the lowest curve (1·07 soda) seem to have been defective.

With the exception of these two sets of briquettes, the results plot into curves, the parallelism of which is remarkable.

Cement B gives results on the whole similar to those of Cement A. In this case, as in the case of Cement A, the highest point is reached on all the curves at the same period, but 7 days later than in Cement A, and unfortunately, the curves are not yet long enough to show whether the recovery has begun at 49 days. This cement begins with greater strength at 7 days when gauged pure than was the case with Cement A, but the effect of soda is a greater reduction in strength.

It is not well to regard coincidences as of much importance in cement testing unless they are shown by a very great number of tests, as the chances of erratic results are great, but the comparative regularity of the curves leads me to believe that they may be accepted as fairly accurate, and that deductions made with caution from them will be instructive.

In the first place it is evident that the strength of the cement is reduced by the addition of soda. This is very apparent at 7 days, at later periods the strength increases at about the same rate in the pure cement as in that to which soda is added.

This seems to point to the reduction of strength when soda is used being due to interruption of crystallization in the very early stages, so that if the cement could be mixed and placed *in situ* in less time than the beginning of setting requires, it is probable the strength would be

greater. The strength attained by the cement and soda so far as the experiments have gone, is sufficient for practical purposes, and as no evidence of future destruction is present there is no reason against the use of soda for accelerating the setting of cement where that condition is desirable.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

FOURTH MEETING—15TH DECEMBER, 1897.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,
PRESIDENT, IN THE CHAIR.

Discussion upon Mr. PROSSER A. H. SHAW'S paper entitled—

"PORTLAND CEMENT,"

and Mr. FRANK E. PRIEST'S paper entitled—

"EXPERIMENTS IN THE ACCELERATION OF THE SETTING OF PORTLAND CEMENT,"

which were read at the meeting on the 1st December, 1897.

Mr. J. WEMYSS ANDERSON said—I can quite agree with the authors of these papers when they say that Portland cement and difficulties go together. I do not know that there is any other department that gives so much trouble as cement testing; we are frequently told that better results can be obtained elsewhere, but it is not always with the same cement. I am sorry that the author of the first paper is not here to-night, as I am afraid I differ from him on one or two points.

In the first place, I think the chemical composition is rather an important item (although the author says that he does not think this is so), as the silica, alumina and the ferric oxide really give you the setting properties of cement under water. Taking the case of "soundness" mentioned by the author: he is right to put it second on the list. I would very much like to put it with "chemical composition," and before "fineness," as I think it really shows the chemical composition of the cement. If we have a large or even

a comparatively slight excess of free lime present, it will not give a sound test. Consequently, I should put "soundness" first, then "tensile strength," and "fineness" last. If you put "fineness" first, it follows at once that that is more important than the "soundness" or "tensile strength" tests.

The fineness of grinding is rather important, but I differ as to size of sieve. If a 5800 mesh sieve (which is too fine for practical purposes) is made the standard, I do not think that you should allow 10 per cent. residue. Whatever sieve is selected the residue should not exceed $2\frac{1}{2}$ per cent. I would suggest that there should be no residue on a 16,000 mesh sieve, and a residue not exceeding $2\frac{1}{2}$ per cent. on a 2500 mesh sieve.

With regard to the tensile strength, my own opinion is that a great deal depends upon the gauging. I do not think it altogether right that a cement should be rejected upon the first test. The greatest difficulty that we experience is getting a standard method of gauging. We frequently have clients who, when the day for testing arrives, bring a few of their own briquettes with them.

As to the percentage of water. I see no mention in either of the papers with regard to this. The author of the second paper does not deal with the subject in the same way as the first author; he simply puts some results before us. This subject is a very important one, and seeing that some advocate comparatively dry mixing, others wet, I think it is a matter that someone present might enlighten us upon.

Another point is the rate of loading during the test. From experiments that I have made I know that this has a great deal to do with the strength. If you take a briquette and use an initial load 2 pounds of shot (which reads perhaps 100 pounds absolute), you will find that the briquette will give you much higher results than if you loaded it slowly, starting from zero. The rate of loading is therefore very important: there should be a certain standard arranged and that standard should become universal.

Finally, with regard to the remarks made in the early part of the first paper, where the author mentions the results of tests—some of which had been immersed in water, and others exposed to air only, those in water giving an average of 330 pounds, and those in air 740 pounds—of course the cementing properties depend upon the amount of ferric oxide, alumina and silica present, as these allow the cement to set under water. The free limes will set in air. When you dry the briquette in air you have two actions going on, consequently

you will get a very much higher value when the briquette is allowed to dry in the air for seven days. I think the mass referred to fell to pieces on account of the fact that the lime had not been turned into a carbonate. When a cement block is allowed to harden in air, it gives a much better result than being placed in water, as a crust is formed on the top in which the free lime is turned into carbonates, in addition to the ordinary chemical action. I think that is the true explanation of the behaviour of the briquettes mentioned by the author, not on account of the lime being hydrated.

With regard to the second paper, I do not think there are any remarks I have to make upon it.

Mr. Arthur Musker said—With regard to the second paper, it is rather curious that among the makers of hand-made concrete flags it is considered that steeping the flags in a bath with silicate of soda very much increases their strength, and so much so that these flags bring 1s. a yard higher price for that reason.

Another thing that we have found in making concrete flags under heavy pressure is that the amount of water added to the cement is of no consequence. The cement concrete can be made as wet as possible, and then when the water is pressed out the result is much stronger than the ordinary hand-made flag, and it matures in rather less than half the time. A hand-made flag will take 3 months; a machine-made pressed flag would be ready for use in about 6 weeks.

I should like to know if the author has tried putting the briquettes in a solution of soda and water after they have been made.

Mr. Thomas Duncanson said—These two papers, which I think the Society is to be congratulated upon having read, bring before us a very fair range of the different questions which are to be met with in the consideration of this question, and we have a large field for discussion. The first paper deals with the subject on orthodox lines, and gives the result of the author's actual experience in using cement. There are several points in the paper that one would like to make observations upon.

With regard to weight as a test of the quality of cement, I think it is almost universally admitted that as a test to be used, weight is nothing to go by. It is somewhat interesting, however, with fresh cement that one has to deal with, to take the weight.

The second point is what Mr. Anderson referred to, *i.e.*, placing "fineness" first in the list of qualities to be asked for. I have no doubt whatever that soundness as a quality should come first.

With regard to fineness, the author gives a very large number of

different specifications. The first three must date from a considerable time since, or else they were for small contracts. We might add some to the number given here. For instance, on the Vyrnwy, the screen was a 10 per cent. residue on a 3600 mesh.

One point as to the wires of the sieve. It is possible that with a sieve with so many meshes to the inch, if the wires are thicker or thinner than the specified size, you might have orifices left in the sieve either smaller or larger than if the wires were of the proper diameter. It is good practice to have some definite specification as to the wires. For a 3600 mesh sieve at the Vyrnwy, the brass wire was $3\frac{3}{4}$ ounces per square foot. Further, another proportion for the size of the orifices in wire screens is that they should be of equal size, *i.e.*, the diameter of the orifices should be half the distance from centre to centre of the wires.

I suppose in the analysis of the oxide of iron Hg. SO_4 means H_2SO_4. The author also refers to the fact that cement should only be tested neat. I suppose the principal reason is because you get reasonable results comparatively soon. You cannot wait long enough for other results.

On the question of adulterants, I agree with the author that they should not be permitted in Portland cement.

As to fineness, I think it is desirable to have a more finely ground cement than commonly used at the present time. The additional cost is not very great, and the inert matter is considerably reduced.

With regard to the second paper, I think the author is to be congratulated on having found out something which is likely to be of considerable use. I took the trouble to make one or two little experiments just to see what the effect was, and no doubt the information is all perfectly correct. I especially was pleased with the rapidity with which you can get a mixture of 2 of sand and 1 of cement to set with soda. It took half an hour with soda, and with water it took $1\frac{1}{2}$ to 2 hours.

Mr. James Morgan said—I am sorry that the author of the second paper could not carry his experiments a little further on. From 30 to 49 days there seems to be a falling off in the strength of cement. I should have expected, if he had gone a little further, that there would have been a reverse of the wave. A point was raised just now about the quantity of water which ought to be used in mixing the cement to form a briquette for testing. In my practice, I have found that one-sixth of the weight of water to that of cement is the fairest proportion that you can use. I made some experiments, years ago, to find out what effect the addition of water to cement would have, and I found

that 10 oz. of water to 64 oz. of cement gave the best results. If you increased the 10 oz. of water by adding ½ oz., and so on, the cement in testing gave very much worse results. The majority of good cements would take this 10 oz. of water to 64 oz. of cement, but I found that a poor cement or a hot cement would take far more water to mould it. In this case the tensile strength was very poor. The acceleration of the setting of cement I do not think is a good thing for ordinary works, but it is a splendid expedient to enable concrete to set quickly in hydraulic works.

Mr. Henry H. West said—I only rise for one or two remarks. It occurred to several of us, at the last meeting, as to how the author of the first paper measured his pressure of 30 tons to the square foot. I think it was Mr. Duncanson suggested that it might not be the weight of the grain only, but the weight of the superstructure of silos on the head of the column, and as the concrete is further reduced to a comparatively small area, probably that was the equivalent of the 30 tons to the square foot. I think it would be interesting to know from the author what the basis of his calculations was.

I think, too, that the weight of the grain would not come directly on the bottom of the silo, from the fact of it arching itself, as it were, and converting the pressure into a lateral pressure more or less. I believe that is the result of investigations made in connection with the silos at the north end of Liverpool.

One other matter which does not apply only to cement. I have always had a feeling that anything like a rigid system of standard tests is an undesirable thing. While for commercial purposes, standard tests are good and useful things and may be made the basis of a contract between a buyer and seller, it should, after all, be left to the Engineer who is contriving a structure to decide what particular tests he needs for his own particular purpose. I make that remark because the author of the first paper, after describing the several different specifications of different people, says that it goes to show the difficulties of manufacturers in meeting various requirements, and tends strongly to show the advisability of a standard fineness. Now whether that is desirable or not is a matter I do not profess to judge of, but generally speaking, with regard to all sorts of material, a standard test I think should be made with qualifications according to the particular purpose for which the material is required.

As to the larger particles in a cement expanding, I do not know whether anybody here has any experience of such a thing actually occurring. I should have imagined that the adjustment of these

changes is made by internal re-arrangement of the particles, but I cannot say whether this is so or not, but I should not expect that the stability of a structure would be disturbed by any condition of that kind.

I remember a good many years ago having to do something with cement, and the remark in the first paper, that a sufficient quantity of water should be used, brings it to mind. The cement was applied dry and then washed over with a brush, and that set the hardest of any cement I ever met with.

In the second paper, the subject is attacked from a point of view that to me is perhaps more interesting. The use of cement in stopping a leak is an interesting thing, and very often is the only course that can be adopted, and I think anything that will enable you to mix your cement and get it to the place where you want to apply it, and then make sure that it will set at once, is what you want. I do not suppose that anybody looks on quick setting cement as desirable for permanent works, but for a thing that is intended just for an immediate purpose, and then to be cleared away afterwards when the immediate pressure is done with, I think the actual strength of the cement is a comparatively small matter.

Dr. H. S. Hele-Shaw said—For some considerable time I did the cement testing at the University College myself, and I found it the most unsatisfactory part of the whole of our testing work. With other tests, I might say now, after 8 years' experience, we very rarely have a question raised of any kind, but with cement it is a continual source of trouble. If it were not for the information we glean, and for the extremely valuable results we obtain, I should put in large type on our notice "No cement testing undertaken."

The way in which we are treated is this. A sample of cement is sent to us, and some other testing laboratory is supplied with the so-called same cement, and the results are compared. Of course there is no absolute means of checking the result. I merely point out that cement testing is for that reason in a very unsatisfactory state, but if that were all we might not grumble, but there are so many difficulties in themselves, one of them being, as Mr. West suggests, that each man should specify the qualifications that he requires. It is difficult enough with steel but far greater with cement. The fact is, that a number of people use cement who have never thought of its composition, the effect of air, heat, moisture, and all sorts of things upon it.

Sometimes samples come to us in a bag, in a box, sometimes wet, sometimes dry, some in large and some in small quantities. With all

these things I think it is time that the leading Institution did try and take up the matter with a view to getting some better system.

As to mixing, I can make a cement, a fairly good cement, almost anything. As to the water, it is very much affected by the ramming, and you can hammer in the briquettes and get results very much higher than ordinary, and sometimes one is tempted to do so. We have been obliged to use a certain sized rammer.

Now as to the wire, the author of the first paper does not mention the gauge of the wire. We try to get a certain gauge of wire; without that it is absurd.

As to the question of water, we are often obliged to take our own course about that. Some will have between 15 and 20 per cent., but you want a good deal of judgment.

I have made a calculation as to the pressure on the arches mentioned in the first paper, and find that the total weight comes to about 30 tons per square foot. The pressure is really sustained on the walls and not on the bottom, owing to the grain forming an arch.

About the curves in the diagram of the second paper, the pure cement goes on to rise until after about a year, when it remains stationary. I think the same results will be attained with the soda, and that it will not fall if the tests are continued.

Mr. W. E. Mills said—One remark as to water. I should be glad to know whether either of the authors have experimented at all as to the quality of the water used. The second paper does not mention it, but at the end of the first paper there is a distinct reference to it. He evidently from that considers that the purity of the water is an element to be observed as well as its temperature, and I am rather led to ask this question owing to a remarkable instance some years ago.

I was consulted with regard to the rebuilding of a portion of a river wall, which had had a large breach made in it owing to a heavy storm. The owners came to me, and I persuaded them to let me draw up a specification of how the work should be done, and of course part of that specification was that cement should be used which would be equal to stand a reasonable test. In a neighbouring town were two public laboratories, each of which undertook testing, and I selected one of them as being the place at which the cement should be tested. We will call them A and B. The makers were told that the cement must be of the very best, and I transmitted a sample to laboratory A. Several briquettes were made and tested. I think the strain it had to stand was 450 pounds to the square inch. The tests broke at from 300 to 320 pounds. This was rather serious. I thought possibly

some little carelessness might have been made in the mixing, but new briquettes did not improve on testing by more than 4 or 5 pounds. There was nothing for it but to reject this lot of cement. That brought the makers down upon me with samples of exactly the same cement, with proofs from Mr. Kirkaldy that they had stood 700 pounds with the greatest ease. I told them to go and test it at the laboratory, and they got the same result. They confessed themselves puzzled. Would I have any objection to allow the same cement to be tested at laboratory B? I agreed, and accordingly the same sample was taken to B and mixed carefully, and rammed and tested under the same conditions. At B we got the tensile stress required. The fracture of the two sets of briquettes showed a remarkable difference. Those at A had a bright yellow effect entirely absent in B. We were led to connect the failure with this curious effect. I was not able to find it out, but I permitted the cement to be used, and the work has stood very well. The professor in charge of A was exceedingly anxious to fathom the result. He wrote afterwards that the water supplied at the time to the laboratory was not, for some reason or another, as pure as it might be. He afterwards tested some of the sample with rain-water, and he had no difficulty in obtaining the same results as at B.

It occurs to me, however, that probably some of the failures that we get in these tests might be due to the water and its chemical constituents.

It seems to me that if, as some of the speakers have hinted, it is desirable to define a standard, it would also be desirable that the water used should be of a standard, either distilled water or water of a particular chemical constituent, or that, at any rate, in comparing one sample with another, the briquettes should be made with the same water.

Professor H. S. Hele-Shaw said—As I was the professor at A referred to, I might explain that the water was chemically impure, being drawn from a new tank which was painted with red lead inside.

The President, Mr. George Farren, said—The author of the first paper exhibits a model concrete arch, the original of which he says supports a load of 30 tons to the square foot. It seems to me that is a very large strain. The stresses on the Forth Bridge are a little over $6\frac{1}{2}$ tons to the square foot, those on the Tower Bridge are only about 4 tons. Perhaps the author will explain this.

Mr. Frank E. Priest, in reply, said—Before replying to that part of the discussion which affects myself, I should like to say some-

thing with regard to the first paper. I only wish to speak on one point, the sand test. I do not think the author has left it altogether in a satisfactory condition. I cannot resist pointing out that the author has shown a reason in one part of his paper for what he had condemned in another part, and I think from conversing with a great many engineers in this country that that very unfortunate insularity with which we are all afflicted is very prominent in the case of the sand test. I do not think we are wise to throw it on one side because it has difficulties. In these days of sophistry the weakness of a cement in work is due sometimes to the addition of a material as fine as the finest of the cement. It is known that sand may be added to cement without reducing the strength so long as the proportions are such as to ensure the cement being ample for the cementing together of the particles of sand, and adulterants may be added in the same way if of suitable material. Kentish Rag appears to be very suitable for the purpose, and can be ground to any size so as not to be detected on the sieve. It is evident, also, that if it does not reduce the strength of the cement its presence will not be detected in the machine. If, however, three parts of sand be added, the sand and the adulterant together are greater in quantity than the cement, which is reduced by the displacement of the adulterant, is able to hold together, and thus the presence of the adulterant is detected in the machine. The cement is in most cases used with sand, but however it is to be used, it would be better for the user to buy the sand as sand than to pay for the mixture as cement.

Before leaving this question I want to say also that I am afraid the author has done an injustice to a dead man when he quotes Mr. Grant. He has used that quotation to show that sand testing is not at all reliable. I do not know where the extract comes from, but I purpose reading to you what Mr. Grant said within 8 years of his death, having spent the greater part of his life experimenting with cement.

> Nothing has done so much to raise the quality of cement in Germany as the adoption of the system of testing its strength when mixed with three times its weight of sand of a standard gauge and quality, and made into briquettes, which are tested when twenty-eight days old. To give a clue to any cause of discrepancy or disappointment which may arise, and for experimental purposes, it is desirable to ascertain its weight, degree of fineness, time of setting, and, where there are facilities for it, the chemical character and other features of cement. But if it give the required strength when mixed with sand after four weeks it may be accepted without fear, and the specification be much simplified. . . . . .

The Author has for several years past used the test of cement with sand, and would have adopted it long before he did, but for the occasional and temporary difficulty it involves at the commencement of works carried on in public thoroughfares, of waiting a month to know the results. . . .

Numerous experiments, by a great number of observers in different countries, have shown beyond dispute that heavy, well-burnt cements, which when tested neat have given high results, have notwithstanding, when mixed with sand, turned out disproportionately weak. Even when the important test of fineness is coupled with that of weight, the strength of cement if tested neat does not always correspond with its strength when mixed with sand. The only thing wanting to make this (sand with cement) test perfect is time, *i.e.*, to be able to wait for the results months, instead of weeks. . . . . .

The test with the neat cement at the end of seven days is of little more use than to show approximately, by comparison with the tests made at a later date, whether the cement has increased in strength. The later tests are of most value, and especially those made with sand.—Proc. Inst. C.E., Vol. LXII., p. 99, *et seq.*

With regard to the discussion on my own paper I feel that there is very little to say.

Mr. Anderson said that neither of the authors had referred to the quantity of water used. I have not expressed any opinion as to the quantity to be used. I have stated what quantity was used in these experiments. The quantity was high intentionally. The soda briquettes began to set so quickly that if the cement was kept dry the difficulty in getting it into the moulds in time would have been much greater. On the same question other speakers referred to the quantities to be used in work. Of course you should, in testing, use only that quantity of water which the cement requires, otherwise you do not get a fair result, but it does not follow that this is the quantity of water to use on the works. It is one thing to pound into a mould and quite another to get concrete or mortar into position on the works, and whatever advantage you gain by getting the water down to its theoretical weight you lose by the spaces which are not filled at all.

Sloppy cement, which never is as sloppy as it looks, because the top is always very much wetter than the bulk, is not, therefore, so disadvantageous as it would appear to be.

With regard to Mr. Musker, I know nothing of the effect of silicate of soda when used for steeping the flags in. Of course silicate of soda would act for totally different reasons as applied after the making of the flags to the way that soda crystals would act in the gauging.

Mr. Morgan asked whether I intended to carry these curves on. I

mentioned at the last meeting that I did intend to do so, and if anything arises out of them I shall be very glad to communicate it.

Mr. West raised the point as to the application of the knowledge which is attained in this way. I can only say that I do not think the difficulty would be very great. I submit a sample of quick setting in the briquette on the table.

With regard to the curves, the thing that surprises me about them is the parallelism of the curves from 21 days onwards. I hope to carry out that part of the curve again with a separate series of experiments, to see whether anything at all similar is arrived at. It may be that there was something the matter with the particular cement.

Mr. Mills asked a question as to the quality of the water. I cannot say that I have any knowledge that is worth stating as to the quality of the water. I think in Liverpool the quality is pretty uniform. I mentioned that the water was all drawn from the Liverpool mains.

CORRESPONDENCE.

Mr. Prosser A. H. Shaw, in reply to the discussion, wrote :—

The author wishes to thank the Liverpool Engineering Society very much for the interest they have taken in his paper, and is much pleased that it has brought forth a useful discussion, which is so essential in all such papers, and he begs to reply, *seriatim*, to the several points raised in the discussion.

With regard to the remarks of the President, the total weight due to the superstructure, grain, &c. = 270 tons, and the concrete surmounting the capital of the column being 9 square feet gives a compression strain of 30 tons per square foot on the concrete over the column.

Dr. Hele-Shaw has evidently verified this by his remarks later on in the discussion.

The author wishes to add that the store has been fully loaded during the last ten years, and in no case, out of 102 columns supporting the superstructure, &c., has there been the slightest sign of a fracture.

Mr. Wemyss Anderson says he would like to put "Chemical Composition" before "Soundness." The author, while admitting that chemical composition is a most important factor in Portland cement, and following the treatment of the subject as put forward in his paper, *i.e.*, from an engineer's practical point of view, can scarcely agree (doctors do not always agree) that the ordinary engineer can take chemical composition for his basis.

What he stated in his paper was that "Chemical Analysis had no exact "relation to the strength of cement," and would add that it is chiefly used in detecting sulphur and magnesia, which are dangerous elements if in excess, also, the laborious task is more a matter for the chemist than the engineer, who can arrive at the true value of Portland cement much more readily, and, as Mr. Anderson states, the soundness test shows the chemical composition to a great extent.

Fineness.—The author is still inclined to consider "Fineness" a most important factor which cannot be over estimated, and he considers he cannot impress the fact too much on all users of cement. There is no doubt that in cement, mortar, or concrete, each particle of the aggregate should be coated with a film of cement, and to ensure this the essential is a finely ground cement.

There is no doubt whatever that all granulation or residue is inert, and that fine grinding materially improves the quality of the cement itself. The 16,000 mesh sieve would be both tedious and troublesome for engineers, whose time is very material, and the author, after due consideration, is yet of the opinion that the most useful and economical grinding for general use, which, he believes, would be readily met by the manufacturers if made uniform—and in most cases they would be only too glad to have a remedy for the many extraneous grindings they are so frequently troubled with—would be, say, not exceeding 10 per cent. residue on 5800 mesh sieve.

As to a standard gauger, they may be very useful, but the author is more inclined to handle the cement, which can readily be done after a little practice, and it rather gives you an analogy to the manipulation of the concrete. In many cases the cement gets quite different treatment on the works than in the testing room ; the latter remark refers particularly as to water, which the author purposely avoided in his paper, as he did not give a table of results, and, although always noting minutely the quantity of water used in gauging, yet considers it a matter for the manipulator. In most of the tables of tests we see, no doubt, the minimum quantity of water used, but it is questionable if it is generally justifiable. Some cements take a larger quantity of water than others, and it will vary almost with every different sample, a quick setting one taking more than a slow setting one, fineness also alters the quantity. 17 to 20 per cent. is an ordinary laboratory practice, but the author would not like to make this a limit.

As to Mr. Duncanson's remark, $Hg\,SO_4$, is clearly a misprint for $H_2\,SO_4$.

As to the quality of water, the author has used the Dublin Vartry water in all his experiments, the following being its composition :—

One imperial gallon (70,000 grains) contained—	
Total solid matters	4·20
Including—	
Albuminoid Ammonia	0·04
Free do.	0·02
Nitrogen in Nitrites and Nitrates = Nitric Acid	traces
Chlorine	0·990
Equal to Chloride of Sodium	1·640
Hardness before boiling	1·7°
Do. after do.	1·6°

Microscopic examination satisfactory.

The author hopes Mr. Frank E. Priest will see the error of his remark as to any "injustice," as he says, "to a dead man," when he consults the

Proceedings Inst. C.E., Vol. LXII., page 249, where, I think, he will find the quotation from a useful paper by Mr. Grant on Cement.

The author regrets extremely his inability to attend the discussion, and trusts his replies fully meet the several querists.

In bringing this paper before the Society he avoided the general tables of tests which are given in so many records, but endeavoured, in as plain and concise a manner as possible, to bring before the members some practical views, which he considered might be beneficial and useful to engineers who might not have the time and means of making exhaustive experiments on such a very important subject.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

FIFTH MEETING, 5TH JANUARY, 1898.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,

PRESIDENT, IN THE CHAIR.

The President, Mr. GEORGE FARREN, said—In introducing Mr. Walwyn White to the meeting I may state that I have, in common with all other engineers, given a considerable amount of thought to getting bales and packages from ships without breaking bulk, by an overhead railway, to Manchester.

But more than this, I have thought of making an aërial tramway over all the great warehouses of Manchester itself, so that on a bale of goods coming from the ship it would be delivered in Manchester, not on the ground floor, but on the top of the warehouse, from whence it could descend by gravitation to ground level, having been dealt with and put in a finished form on its way. There was an enormous fund of money which might be drawn on to do this.

There was, firstly, the sending of lorries to the railway station, as at present in Manchester, carting to its destination, unloading at its destination, and eventually hauling to the various heights of the warehouse in detail where the materials were to be dealt with.

This, at any rate, would about half cover the hauling expenses on such work, and the traffic then would only be the outgoing traffic, and Manchester being only 80 feet above Liverpool, and adding 100 feet to the height in 35 miles, would only be 1 in 1030, this would not be a large addition to make. Of course it would mean the lifting of these weights to the height of (say) 100 feet.

I found, however, on considering this question, the difficulties surrounding it were so enormous that it is, I think, beyond the capabilities of any individual member.

I hope, however, the paper we are going to hear will greatly facilitate the object mentioned.

10

AËRIAL ROPEWAYS.—*J. W. WHITE.*

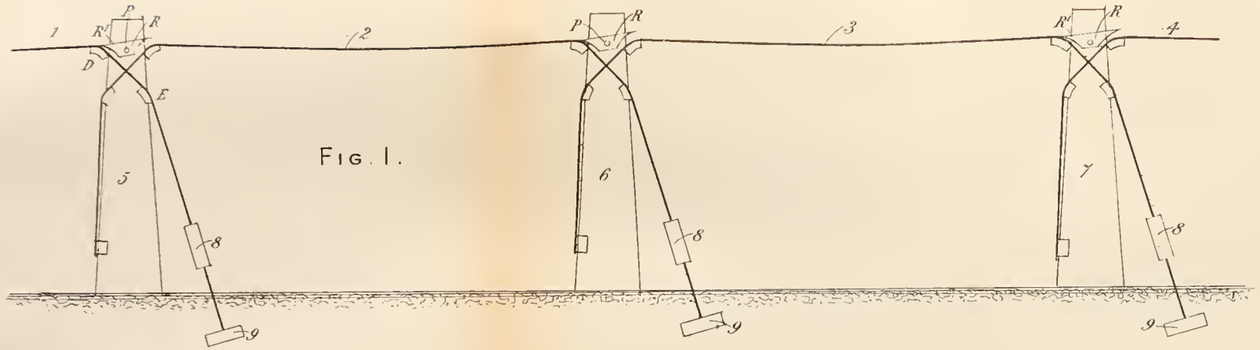


FIG. 1.

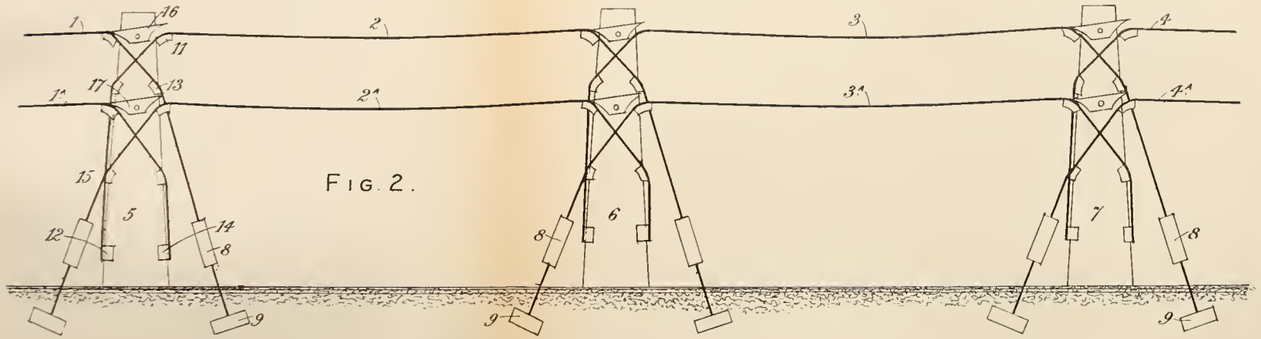


FIG. 2.

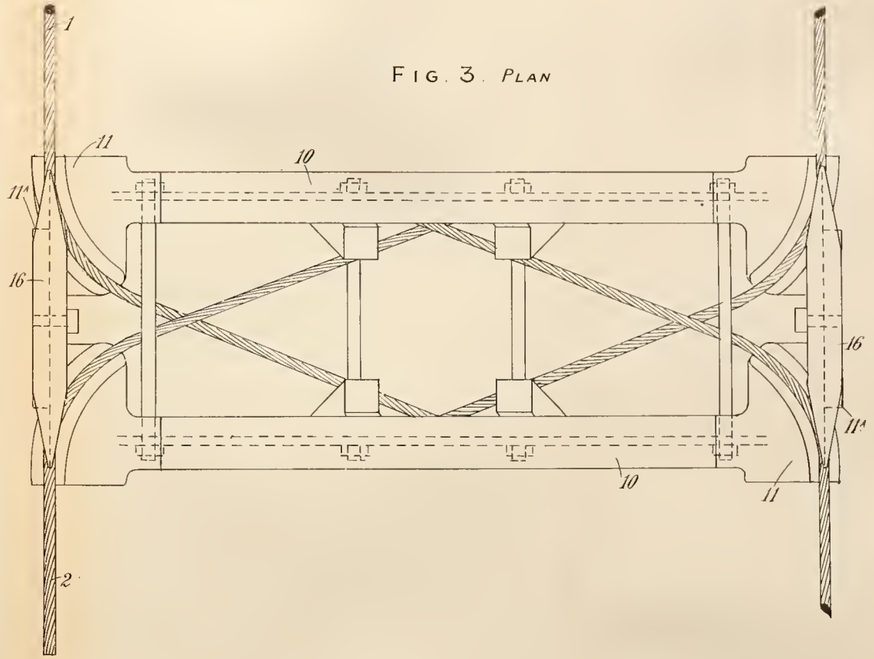


FIG. 3. PLAN

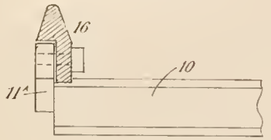


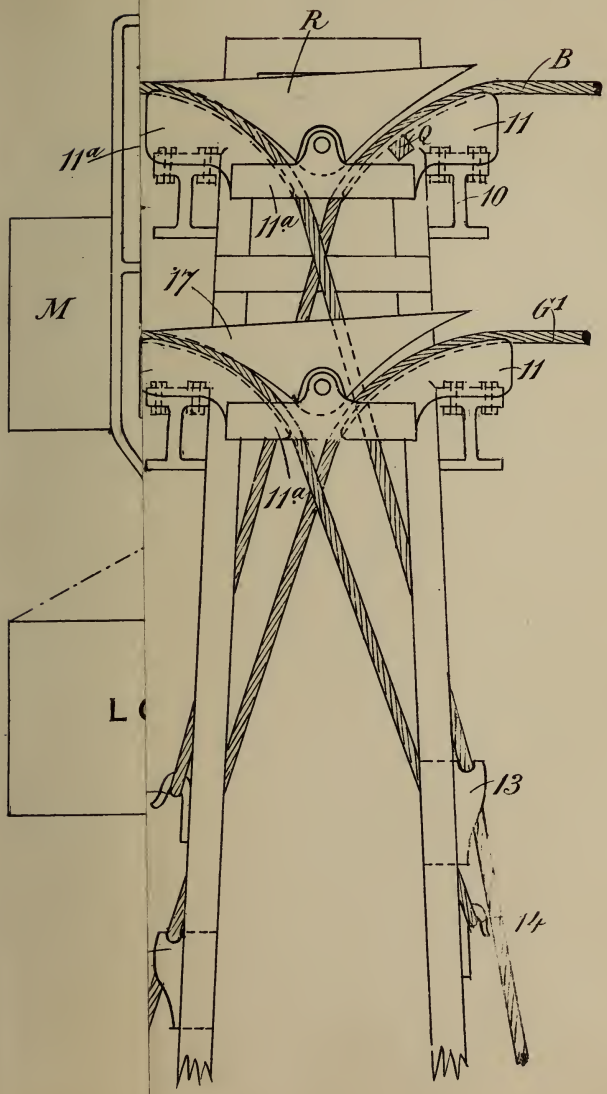
FIG. 4.

SECTION OF ROCKING RAIL ON CENTRE LINE

George Reed & Co Lithographers, 64, Stanley Street Liverpool

PLATE III.

FIG. 6. *FRONT ELEVATION.*



AËRIAL ROPEWAYS.— *J. W. WHITE.*

FIG. 5. *END ELEVATION.*

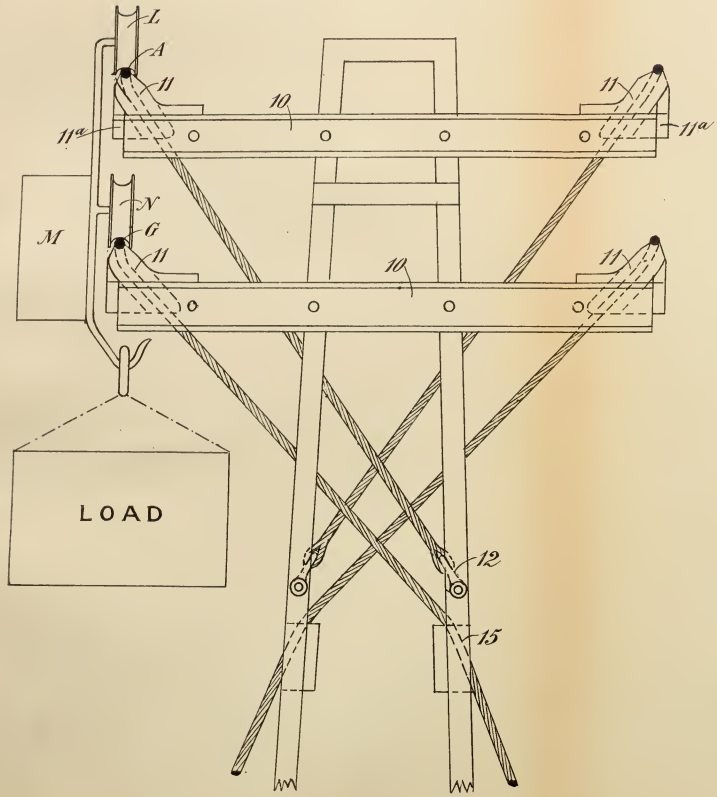
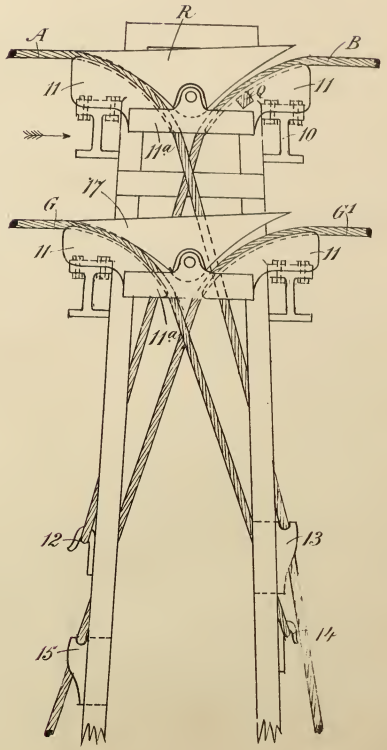


FIG. 6. *FRONT ELEVATION.*



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AËRIAL ROPEWAYS. — *J. W. WHITE*

FIG. 7

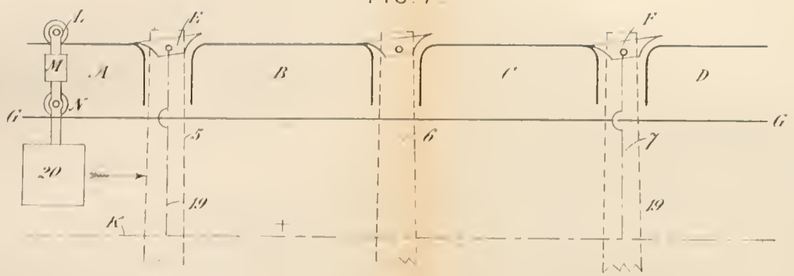


FIG. 8

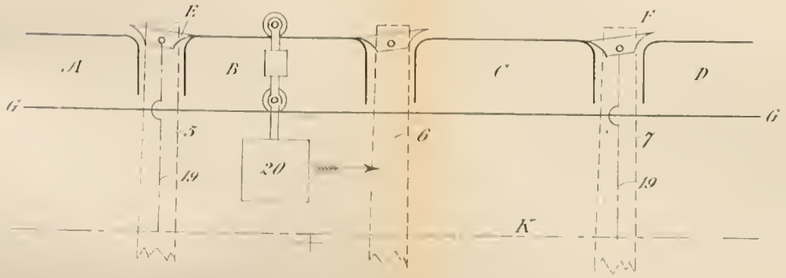


FIG. 9.

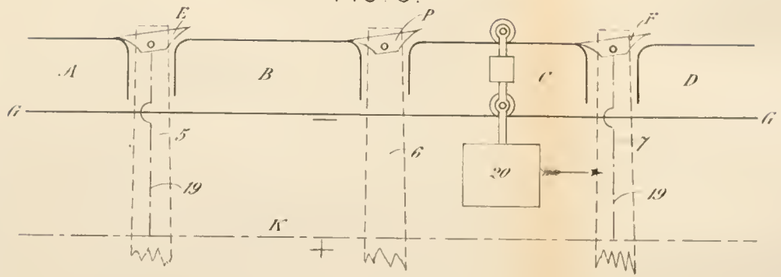


FIG. 10.

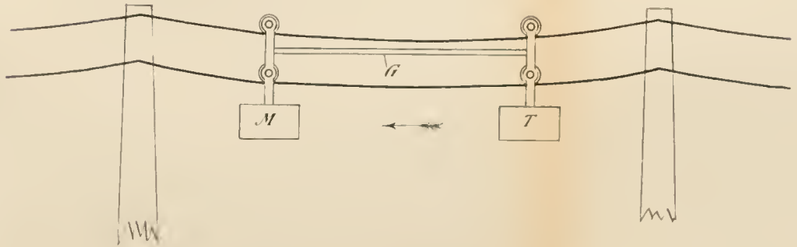


FIG 11.

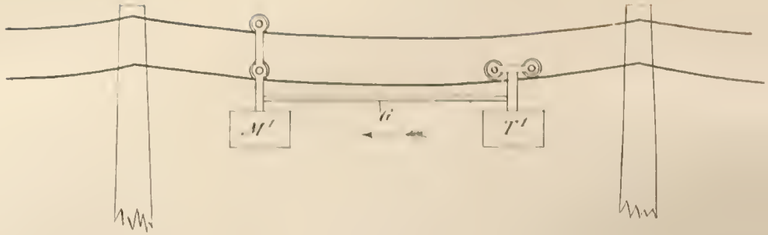
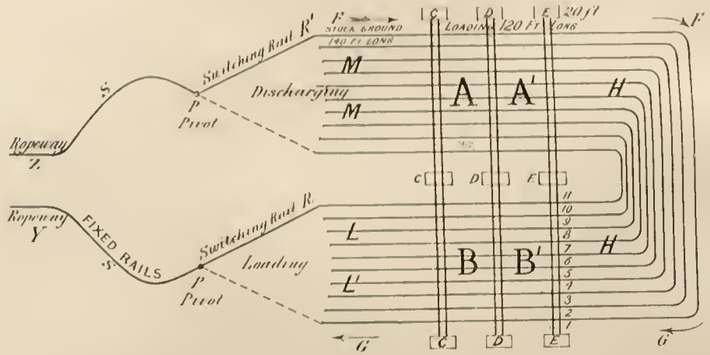


FIG. 12.



AËRIAL ROPE RAILWAYS, WITH SPECIAL REFERENCE TO TRAFFIC BETWEEN LIVERPOOL AND MANCHESTER.

By J. WALWYN WHITE.

It was only a month or two ago, in this very building, that Mr. Worby Beaumont reproached the merchant princes of Liverpool, that they had not adopted some less costly means than at present in use, for the transport of the immense amount of merchandise that daily passes through this port to Manchester and other manufacturing towns, and *vice versa.*

A short time since, most of you will remember, one of our leading firms of shipowners made an effort to remove this cause of reproach, by inviting competitions for the best method of dealing with this heavy traffic, based on the assumed weight of 1000 tons per day from Liverpool to Manchester and the same quantity back again.

Several schemes were forthcoming in answer to this invitation, and a committee was formed to consider them, but was unable to recommend any one scheme for adoption.

I understand the methods proposed included :—

(*a*) Use of self-propelled vehicles, running on the ordinary high-roads, in some cases the carrying vehicle to contain its own motive power, and in others, a separate tractor or locomotive to be employed to haul one or more loaded wagons behind it.

(*b*) Use of tramways, with ordinary grooved tram rails, running through or along the ordinary highways.

(*c*) Use of independent narrow gauge light railways, on which the loaded horse lorries were to be conveyed, without break of bulk, on what the inventor terms "transportation cars."

Then there was the well-known Plateway Scheme of Mr. Alfred Holt, which undoubtedly has many supporters, and there was also a further scheme suggested to utilise the existing small canals, by draining them and laying down railways on the track thus provided.

Briefly glancing at these five main schemes, it will be at once evident that any plan of traction on the existing highroads for such

an immense traffic must necessarily end in failure, even assuming a perfect self-propelled vehicle, which is yet to be produced.

In the first place the coefficient of traction on a highway is about six times as great as on a railway, the actual figures being:—

On an ordinary macadam road, on the level, in good repair ... ... $\frac{1}{50}$ of the load.

On a railway, on the level ... ... $\frac{1}{280}$ of the load.

Such a large waste of power would prevent any chance of commercial success, and the extra wear and tear of the roads would undoubtedly have to be recouped to the various highway authorities. Whilst we have the assurance of no less an authority than Mr. Beaumont, that heavy loads cannot be economically conveyed along ordinary highways by self-propelled vehicles, Mr. Beaumont states that such a vehicle, capable of carrying a load of 10 tons, would itself weigh 17 tons, and he further says that the cost of the actual working of hauling heavy traffic on roads amounts to $3\frac{3}{4}$d. per ton mile, reckoning coke at 18s. per ton; figures which need no further comment.

As to the second plan of using Street Tramways with grooved rails, the first objection already named would hold good to a certain extent, as owing to the difficulty of keeping the grooves of the rails even moderately clean, the coefficient of friction is very high, being about $\frac{1}{80}$ of the load, or $3\frac{1}{2}$ times as great as on a railway, whilst in times of frost and snow the grooved lines are practically choked up, rendering traffic difficult and occasionally impossible.

Then as a large proportion of such a large traffic would have to pass during the night-time, the noise would be a public nuisance to householders on the route of the tramways, and would probably not be allowed by the public authorities.

The third plan of a narrow gauge light railway undoubtedly, to my mind, would be the most feasible, were it not that the immense cost of land between these two large centres, involving tremendous compensation for severances, coupled with the large number of bridges and viaducts that would be required, put the scheme altogether out of the sphere of practical utility from a commercial point of view as far as *cheap* transit was concerned.

Mr. Holt's Plateway scheme, I think, shares some of the disadvantages of both the last two plans, as the coefficient of friction would be quite as high, if not higher than on street tramways, the flat rails with the side flange offering a splendid asylum for dirt and

rubbish, and setting up a large frictional resistance with the sides of the flat wheels of the vehicles, whilst the difficulty of the cost of land, compensation for severances and costly bridges would be nearly if not quite as great as with a light railway.

Then, it may be objected, why not utilise the existing main line railways to carry this traffic. The answer is, that with the conditions obtaining in this country, the great railways cannot convey large amounts of traffic at what are popularly known as cheap rates. They have to pay enormous sums of money for the land they occupy; they have costly bridges and tunnels to build and subsequently maintain; they are bound to maintain costly signals and signalmen for absolute block system of running; they are bound to keep up high speeds on their lines with their goods trains in order to keep out of the way of their passenger trains (which high speed is obtained at the expense of economical haulage), and owing to this high speed they have to construct and maintain in perfect order very costly permanent way and rolling stock. The latter has to be of a very substantial kind, involving a very large proportion of dead tare weight to the actual paying load, in fact, as a rule, an ordinary railway wagon, as provided by the L. & N. W. Railway, or L. & Y. Railway, carrying a load of eight tons, will itself weigh nearly six tons, or a loss of over 40 per cent. of the hauling power and attendant wear and tear of permanent way and rolling stock.

A further consequence is that the railway companies are unable to provide separate wagons to carry the small loads of about three tons or so, which is the average load of the large horse lorries such as we see in Liverpool and Manchester, and consequently have to erect and keep up enormous and costly warehouses at their loading and unloading stations, involving a large expenditure for the handling of goods at each terminii.

Of course if it were possible to load the railway wagons direct from the ship, or *vice versa*, this last objection would be greatly lessened, but unfortunately this is not possible. Owing to various reasons it appears to be absolutely necessary to load goods from inward ships either on to the quay, or into lorries which will run along the quay ways and ordinary streets, and for the haulage of which there has yet been no efficient substitute found for the horse. Even if this objection could be got over in Liverpool, there still remains the absolute necessity of loading the goods at Manchester and elsewhere from the big railway wagons into horse lorries for conveyance to the various mills and manufactories which utilise the imported goods.

The same arguments hold good with respect to traffic the other way: from the manufacturing towns around Manchester to the shipping port of Liverpool.

It appears, therefore, that any scheme which will work commercially, must absolutely provide for the conveyance of ordinary horse lorry loads of about 3 tons or so, without any break of bulk or unnecessary handling from the ship's side to the manufactory and *vice versa*.

Of the various schemes submitted, the author thinks there is no doubt that but for the fatal objections already named, Mr. Calthrop's plan of a narrow gauge light railway, hauling the loaded horse lorries, without any handling or break of bulk, would have been the best, both from an engineering and a commercial point of view.

This being so, it occurred to the author that any project which would retain the advantages of Mr. Calthrop's plan without its attendant disadvantages would meet the case, and the system of carrying the loads in the air (out of the way of ordinary street traffic, and avoiding all question of compensation for severances, purchase of costly land or building costly bridges) by means of Aërial Ropeways seemed to meet certain of the conditions.

Unfortunately, however, ordinary Aërial Ropeways would not meet all the requirements of the case.

An Aërial Ropeway, as you are all aware, generally consists simply of a steel wire rope stretched from one terminus to the other, supported at intervals by standards, and strained by a suitable tension arrangement at one end. Along this rope the carriers run, each carrier consisting generally of a pair of grooved wheels, suitably mounted in a frame from which is pivotted what is called the "hanger," to which a bucket or box is suspended, which carries the load, the centre of gravity of the load being vertically underneath the carrying rope. Usually one rope is used for carriers going in one direction and another rope for the carriers going in the return direction, and the hauling of the load is generally performed by means of an endless hauling rope, to which the carriers are attached by automatic gripping devices, of which there are several patented designs in use, each good of its kind. This hauling rope is driven by a driving drum usually fixed at the upper end of the ropeway or section, together with (generally) a tightening drum, whilst it goes around a large horizontal sheave at the other terminus, which sheave generally travels on a carriage along a short inclined railway, down which it is drawn by a weight, so putting the required degree of tension on the hauling cable.

In another system of ropeway the carrying rope itself moves along,

the load being suspended from a saddle having a pair of *V* shaped jaws, which grip the rope, which thus hauls the load along with it.

The advantages of Aërial Wire Ropeways are very great, and not the least is the low cost of construction, as no elaborate ballasted, drained, levelled and fenced roadway is required, such as is necessary for every other kind of transportation: merely a small foundation is needed every 200 or 300 feet or even greater distances, where the supporting standards are placed. There are no costly tunnels or bridges required, merely extra high standards in case a river or other obstacle has to be crossed.

The traffic is carried high over the heads of ordinary street traffic, across fields, out of the way of plough or reaping machine, cattle or wagon, and without interfering with agriculture in any way. The service is thus free from the troubles of an ordinary railway, and is not affected by frost, snow, fog, surface traffic or other obstacles.

A further advantage of Wire Ropeway is that the quality of the very high tensile strain of drawn and annealed wire can be utilised for carrying the loads, this tensile strain amounting to 80 or even 130 tons per square inch in section of the steel used, as against some 30 tons in ordinary steel.

These ropeways have hitherto, however, suffered from several great objections, which have prevented their use to anything like the extent that their great advantages would seem to warrant, and the author has tried to overcome these difficulties, with what success he leaves you to judge.

These disadvantages are briefly as follows :—

(1) Owing to the fact that only one rope is used, from one terminal to the other, to carry the load, it follows that this rope must be strong enough to bear the necessary straining tension throughout its whole length (less an allowance for the friction of the rope in the supporting saddles) due to the aggregate of the whole total load that may be on its whole length at any one time. For instance, suppose a ropeway only 2000 yards long, with loads of 20 cwt. spaced at intervals of every 30 yards along its length, the aggregate load on the rope would be $\frac{2000 \times 1}{30} = 70$ tons nearly, and the rope would have to be strong enough to carry this weight and also the much greater corresponding strain due to the tension at the ends of the rope to keep it to the necessary catenary curve from standard to standard, less the amount of saddle friction already named, say some 200 to 300 tons or so, depending, of course, on the amount of deflection allowed on the

catenary curve of the rope and the length of each span, the formula being for the tension on the centre of the rope, when the load is at the centre (for load alone).

$$T = \frac{S.L}{4V}.$$

Where T = Tension on rope in tons.
S = Span in feet.
L = Gross Load on Span—in tons.
V = Versed Sine in feet.

V generally varies from $\frac{S}{12}$ to $\frac{S}{20}$.

It will thus be seen that even with such small loads as 20 cwt. the strain on the rope is very great, so great indeed, as to make it practically an impossibility to carry much greater individual loads, and yet this is only about one-fourth of what we want to carry.

(2) A second objection is, that if this long rope got worn in any one place, owing to a steep gradient, or a long span, or soft material, &c., the whole rope would have to be renewed, while perhaps all the rest of the rope is good and sound, or else a new piece must be spliced in, either operation involving the complete stoppage of the whole line.

(3) Curves cannot be made with this one rope, which must go straight from one point to another, and if it is desired to go round an obstruction, or deviate from the straight path, what are known as angle stations, or horizontal bends, are used, at which the cars have to be detached from the carrying rope, and passed by hand or gravity, past the apex of the angle, and so to the next section.

(4) Turnouts or shunts from the main ropeway cannot be made without a shunting station, similar to the angle station just named, involving the removal by hand of the load from one rope to the other.

(5) Only one rope can be conveniently used to carry the load. Where two ropes are used (when it is desired to carry heavier individual loads and divide them between two ropes) these have to be placed horizontally to each other, and the loads carried on four-wheeled trucks running centrally between the two ropes, two wheels of the truck being on each rope.

This system is very clumsy, it is not convenient to arrange for angle or shunting stations, and it is difficult if not impossible, on a long line, to assure that each rope will always carry just half the load, as it should do.

All these difficulties seem to disappear by the simple expedient of using a separate rope for each span of the ropeway, as you see in this model. (See Fig. 1, Plate II.)

You see the end of one carrying rope 1 is rigidly fixed to a hook at the driving terminus, thence over a saddle and on to the first standard, where it passes over grooved guides *D* and *E*, and is strained to the required tension by a hanging weight, or by an ordinary screw strainer and spring 8.

The next rope 2 is similarly fastened direct to the post or anchorage 6, passed over the grooved guiding sheaves, and so to the next standard, where it passes over the guiding sheaves, and strained by the hanging weight 8, and so on with each separate rope, there being a separate rope to each span. The connection from one rope to the other is made by means of a rocking rail *R*, pivotted at the centre *P*, the ends of this rocking rail resting alternately first on one rope and then on the other.

You see the "approach" end R^1 (if I may use the term) of this rocking rail is grooved out underneath to exactly fit the rope, and to which it is held in the position shown by a small spring so making a good pathway for the wheels of the carrier. When the load gets past the pivot of the rocking rail, this latter rocks gently over to the right, resting on the next rope 2, to which it makes a good pathway, as before; whilst as soon as the load has passed over, the spring pulls the rocking rail back again to the position shown, and is thus ready for the next load.

You see by this means there is a separate rope provided for each span, so that no rope will ever be called upon to bear a greater strain than is due to the maximum load that can ever come upon one span at a time, so that much lighter ropes can be used for a given ropeway with a given duty, but a greater relative tension can be applied at the end of each rope, with a correspondingly flatter catenary curve.

Then, if you wish to repair a rope, instead of having to renew the whole length of ropeway and stopping the whole line, you only need to renew the short length of one span, a matter of small cost and short time.

There are obviously several other advantages by using separate ropes, to which reference will be made later, if there is time (see Appendix I.); for the present, it will suffice to only mention one, which is a very important one. Owing to the end of each rope or span being held by a spring tension device, or merely by a hanging weight, the amount of "sag" or deflection of the rope will vary as the tension strain varies, consequently if two (or more) ropes be used on which to jointly carry the load, one rope vertically above the other, as shown in the larger model (see Fig. 2,

Plate II.), you will see that the strain of the load is bound to be equally divided between the two ropes, and under no circumstances can one rope ever get a greater strain on it than one-half the load, any extra strain that one might get being immediately taken up by the tension weight or spring 8. In the model, you will see that the dead ends of the two ropes are connected by a cord and pulley, to further equalise the strain between the two ropes, although in practice this would not be required if the springs were used.

It will be seen that this arrangement of our two (or more) ropes to which we have now arrived, together with the separate ropes for each span, opens out the possibility of readily and easily carrying very large individual and continuous loads to an extent that has not been hitherto possible.

But this arrangement has advantages in the case of electric haulage far greater still.

Most of you will remember the Telpherage line of Professor Fleeming Jenkin and Messrs. Ayrton and Perry, erected by Professor Jenkin at Glynde, which, it was thought at the time, was going to revolutionise the question of transportation of goods by electric power. It is a beautiful system, and deserves more success than it has hitherto attained, though probably one or two reasons which I will name will partially account for it.

You will remember the Glynde line consists of steel rods $\frac{3}{4}$-inch diameter, stretching from post to post in spans of 66 feet, the end of each rod turning over a cast-iron saddle to which it is fastened by ordinary nuts. Every alternate rod is insulated, and the pathway for the carrier wheels from one rod to another is made by a *fixed* saddle piece between the two rods.

The weak point in this saddle is, that the wheels have to jump the two air gaps between the ropes and the fixed saddle piece and only a very small amount of "slack" on the rods can be taken up.

The insulation was effected by a seating of vulcanite being placed beneath the saddle, melted lead being run in between the vulcanite and iron support beneath, so as to distribute the strain by making a mechanical fit between the vulcanite and the iron.

The train consisted of an electric motor car, in the centre, pushing five loaded skips or buckets in front of it, and drawing five similar skips behind it, the whole train being 132 feet long and covering two whole spans, so forming connection for the electric current from one insulated span to the other, and so supplying the electric motor with its requisite working current.

Each skip weighed 100 pounds, and carried about 250 pounds of clay, so that the nett load of the whole train, covering a length of 132 feet, was about 22 cwt., or less than 12 pounds of nett load per lineal foot of line, which I need hardly say makes the system quite unsuited to our present needs.

It was found quite easy to ascend inclines of 1 in 13 with these trains, with ordinary adhesive wheels on the carrying rods, although only two wheels out of 22 were driven. Each motor received a power of 1500 watts or about 2 H.P., the voltage being about 200, with consequently eight ampères of current per motor, at a speed of four-and-a-half miles an hour.

The tension on the carrying rods was maintained at about two-and-a-quarter tons by means of compensating weighted levers, the rods being round steel bars $\frac{3}{4}$-inch in diameter. The disadvantage of using steel rods is that the length of span is somewhat limited and advantage cannot be taken of the enormous increase in tensile strain of the steel, involved in the "drawing" and "annealing" processes of making the wire strands of which the finished steel wire rope is composed, to which reference has already been made.

It therefore seemed to the author, that although this system of Telpherage was a step in the right direction, still its capabilities as to maximum individual loads and aggregate carrying power were so limited, that some large modification appeared to be necessary, and the large model now before you shows in what direction some of the difficulties at all events appear to be overcome.

You will see it consists of a ropeway, using ordinary wire ropes for carrying the load, supported on three standards, and so forming four spans, each span having a separate double rope, one vertically above the other, the load being carried equally on the two ropes, and each rope in the model consisting of stranded copper wire of $\frac{1}{4}$-inch diameter, although, of course, in practice these would be replaced with ordinary steel wire ropes, of which I have here several various patterns, designed by different makers.

Samples kindly sent by :—

Messrs. Craddock & Co., Wakefield.
Messrs. Whitecross Co., Limited, Warrington.
Messrs. W. B. Brown & Co., Liverpool,
Messrs. Haggie Bros., Limited, Gateshead-on-Tyne.
Messrs. R. S. Newall & Son, Limited, Glasgow.
Messrs. Geo. Elliot & Co., London.
Messrs. Glaholm & Robson, Sunderland.

You will see in this model that the top rope is insulated from the bottom, and each span or section of the top rope is also insulated from its neighbour.

The separate sections of the bottom rope are electrically bonded together, so forming a complete metallic circuit for the return current to the battery, which consists of six Bichromate cells, each of two quarts capacity, arranged in series.

The connecting pathway from rope to rope is made by means of the pivotted rocking rails already described (see Fig. 3, Plate II.,) and which also form the automatic block cut-out for the electric current, as will be shown later.

The electric locomotive, which also carries the load, is of the ordinary type of four-pole Siemens' double armature, the spindle being connected by a spiral wire connecting rod to the worm gearing of the two driving wheels, giving the necessary reduction of speed.

The electric current travels through the top carrying rope *A* (Fig. 5, Plate III.) through the driving wheel *L* which rests on it, thence to the electric motor *M*, returning through the lower driving wheel *N* to the bottom return wire $G\ G^1$.

This is simple enough, and the locomotive travels along as you see. But here came the difficulty. It would be necessary to place a man in charge of each electro-locomotive, or there would be the constant danger of one motor over-running the one ahead of it, with the consequent throwing of one or both of them off the ropeway, and also in the case of very heavy individual loads, of unduly weighting the span where the collision took place. After some experimenting the following appeared to the author to be a simple plan of getting over the difficulty.

If the pivotted rocking rails are insulated from the supports and carrying ropes, and the electric current fed to alternate rocking rails only, instead of to the rope direct, you will see that of two adjacent ropes, only the one on which the end of the rocking rail is bearing will get any curreut (the rope guides 11 and attachments being of course insulated), and as soon as the rocking rail is tipped over by the passing load, it automatically cuts off the current from the rope that the load has just left and by the same movement conducts the current to the rope in front, to which the load has advanced.

If now the rocking rail can be held in this position as long as the load is on the "advance" rope, no current can get to the span behind it, until the rocking rail can get back to bear upon this hinder rope. This is easily effected by placing underneath the rocking rail an electro magnet or solenoid, *Q*.

Referring to Fig. 6, Plate III., *A* and *B* are top ropes of two adjacent spans. *R* is the rocking rail to which the current is fed, with the pivot *not* in the centre of weight, so that the rail normally rests by gravity (or by a spring) on the rope *A*, the load advancing in the direction of the arrow. *N* is an electro magnet of low resistance, in shunt with the rocking rail and rope *B*, so that it is only energised when rope *B* is alive.

Now referring to Figs. 7, 8 and 9, Plate IV., which show a diagrammatic view of three positions, of the electrical connections to the carrying ropes.

Let *A B C D* represent the top ropes of four spans of ropeway, such as shown in the large model.

The bottom rope is represented by $G\ G^1$ the different spans of this being electrically connected into practically one rope.

K is the copper feeding cable, and branches from this go to each alternate top rocking rail *E* and *F*, as shown. (Note that the current is only fed to alternate rockers). Now if the load be on span *A*, Fig. 7, the current will go from *K* through the rocker *E*, which you see makes contact with rope *A*, thence through wheel *L* of the carrier through the motor *M*, bottom wheel *N*, to the return wire *G*, and so back to the dynamo.

Now when the load gets on to span *B*, the rocking rail *E* makes contact with rope *B*, to which it is held by the electro magnet already described. Consequently rope *A* gets no current, and no load can travel along it until the load passes span *B* and gets on to span *C*, when the state of affairs is thus (see Fig. 9, Plate IV.) :—

The motor now gets its current from the feeding cable by way of rocking rail *F*, so that span *B* no longer gets any current, as rocker *P* is dead, consequently the magnet under *E* is no longer energised, so that *E* once more makes contact with rope *A* by means of the spring which always pulls it over on to *A* when the magnet no longer pulls it against *B*.

Thus you will see an automatic and perfectly effective absolute block system is provided, the passing load making its own electric connections without shock, stoppage or reversal of current, or sparking, and no load can ever get within a clear span, either of the load in front of it or of the load behind it, as you will see from the model.

You will therefore see that when a locomotive starts out on its journey, say from Liverpool to Manchester, it will go on uninterruptedly until it arrives at its destination.

In order, however, not to waste so much room on the ropeway, and

further to assist the locomotive in going up the gradients of the catenary curve on the approach to each support, a trailing carrier, carrying approximately a similar load, is connected by a rigid connecting rod just half a span behind each locomotive (see Figs. 10 and 11, Plate IV.,) so that as the load of the motor carrier goes downhill it will pull the trailing load up the corresponding gradient the other side of the supporting post, and as the trailing load goes downhill it will push the motor load uphill.

This connecting rod consists of three steel tubes, connected together in the form of a triangle, suitably braced together, with a coupling hook at each end, forming a light and rigid connection.

The trailing load can either be carried on a carrier having its two wheels only on the bottom rope, in which case the bottom rope would be proportionately stronger than the top one, and which, when too much worn for the heavier load of the bottom rope would still serve for use on the top rope, or the trailing load could be divided between the two ropes the same as the motor load and as shown in the model. In this case the top wheel of the motor would be insulated altogether from the motor and would form a driving wheel only. If this insulation were done by means of a rubber (or similar substance) band around the tread of the wheel it would increase the adhesion or "sticktion," as Mr. Holt calls it, of the wheel on the rope. The current would be picked up from the top rope by means of the top wheel of the trailer and conveyed from it along the rigid connecting rod to the motor in the usual way. You will see at once that this precaution would be necessary, in order not to interfere with the automatic block-working of the line.

It follows, by the use of the trailing load, and by making each span the same length (or multiple) throughout the whole line, that the gradients due to the deflection of the carrying ropes will be equalised, and only the nett gradient from one end of the line to the other need be considered.

Any special gradients due to the variation of the contour of the ground surface, or when crossing highways, railways, or canals, &c., can be modified by making the supporting standards longer or shorter as required.

In case of the difference of level between Liverpool and Manchester (some 80 feet or so) this is so slight as to be practically negligible.

It has already been mentioned that any scheme of transportation of goods from one town to the other must involve the use of horse lorries for the collection and delivery of goods at either end. The

goods are loaded on a loose top or box on the horse lorry, this box being fitted with slings or hooks, so that the whole box with its load may be lifted bodily off the lorry framing, and suspended to the hook of the ropeway carrier without any handling or break of bulk whatever.

It may be urged that self-propelled road vehicles might be employed for this service, but no less an authority than Mr. Alfred Holt has given it as his opinion that no vehicle propelled by turning its own wheels would be of use in collecting goods from some of our Liverpool quays and warehouses, where often enough the wheels are embedded in several inches of dirt, grain, or the miscellaneous accumulations on the ground one so often finds. The same objections would largely apply at Manchester, where the goods would have to be distributed amongst the various factories, mills and warehouses.

We must, therefore, provide a suitable terminus at each end for readily dealing with the loaded horse lorries as they arrive and depart with the minimum of handling and consequent expense.

A reference to Fig. 12, Plate IV., will show how it is proposed to arrange these depôts.

The ropeway itself consists of two lines of carrying ropes, one line for outwards traffic Y, and the other for inwards goods Z.

At the entrance to the terminus, which I will assume to be at the Liverpool end, each ropeway divides by means of the fixed diverging rails $S\,S^1$ to points $P\,P^1$, where the switching rails $R\,R^1$ are pivotted.

There are a series of fixed overhead rails (taking the place of the ropes for convenience) 20 in number arranged in parallel, 12 feet apart, and 120 feet long. Ten of these overhead ways $B\,B^1$, form the loading berths, and ten the discharging berths, $A\,A^1$, the ends of each set of ten roads being connected by the curved fixed rails $H\,H^1$.

Along a width of 120 feet of these loading and discharging berths are arranged overhead electric travelling cranes running along two sets of gantrys at CC^1, DD^1 and EE^1, the length of these gantrys being about 260 feet, and each being 60-feet span. These travelling cranes, of course, are well above the fixed rails, which in turn are well above the ordinary roadway on the ground level.

Suspended on the overhead rails BB^1 are the motor carriers with their corresponding trailing carriers behind them, each of the 10 lines accommodating eight carriers, so that there is sufficient room for 80 carriers to load at once.

The loaded lorry then enters the depôt in the direction of the arrow

G, going along any one of the 11 bays provided for it (numbering one up).

One of the overhead cranes then comes over the lorry, lifts up the loaded box with its slinging hooks, and deposits it at once, without any further handling or storage, direct to the carrying hook of the motor carrier waiting to receive it. A similar load is then attached in like manner to a trailing carrier, and the two connected with the connecting road already mentioned. The starting switch of the motor car is then turned on and the loaded carriers move on a short space out of the way on to the storage lines at $L\ L^1$, there to await their turn for despatching on their long journey, whilst the empty horse lorry goes out at G^1 for a fresh load.

As soon as the line is clear (when the previous load has got a clear span ahead) the train despatcher moves the switching rail *R* to make connection with the particular line on which our load is standing, the current is put full on to the motor, and the two cars, carrying five or six tons of nett load between them, start off to Manchester.

A similar process is adopted with the incoming load from Manchester, which comes along the ropeway to the point P^1, thence it moves along the switching rail R^1 to one of the storage lines *M M*, there to await its turn for discharging. When the horse lorry is ready, (which enters at *F*, in the direction shown by the arrow,) the load is moved along beneath one of the discharging cranes at *A* or A^1. This crane lifts up the loaded box from its carrier and lowers it directly on to the horse lorry beneath, which then passes out at F^1, whilst the carrier is moved along the curved line *H H* on to the corresponding loading berth *B*, ready for another load.

Thus you will see there is no confusion, no handling, no bother, and very little expense, all the work being done by electricity from the generating station.

Such a ropeway as I have attempted to describe would be carried in the open country along the roadsides and across agricultural land without interfering in any way with existing traffic or with the culture of the land, the loads being carried a clear ten or twelve feet from the ground, or even more, with steel supports spaced every 200 feet, the supports being 30 feet high in ordinary cases, and correspondingly higher when it became necessary to cross a highway, railway or canal, in these cases protective bridges being placed underneath the loads to protect the public or traffic passing underneath, in case of accident, or the fear of improperly loaded goods falling off.

On coming to the terminii of the large towns the ropeway could be

carried above existing houses, or along narrow passages between them, and instead of having one large terminus at each end, such as I have described, it might perhaps be better to have two or three smaller terminii.

Although I have only estimated for a total traffic of 1,000 tons per day each way, such a ropeway working continuously day and night (say with two or even three shifts of men) with a working speed of five miles an hour = 147 yards per minute = two spans per minute, could transport a total nett tonnage of 6000 *tons per day* in individual loads of two to three tons, say five tons per train (of motor carrier and trailer) with only one despatch per minute, which could readily be maintained for 20 hours per diem, thus allowing four hours per day for repairs, &c. Of course in such a case the profits would be enormously increased, as the working expenses would be relatively so much less per ton.

I must not omit to draw your special attention to the fact that by this system curves can readily be made by merely placing each saddle or supporting guide at the required angle and forming the pathway from one rope to the other by a correspondingly curved rocking rail.

Shunts or turnouts can similarly be taken off from any support by using curved rocking rails instead of straight ones.

Shunts or branches can thus be taken off to supply any of the intermediate towns, such as St. Helens, Warrington, Bury, Bolton, Stockport, &c., and branches would also be taken from some of the principal collieries *en route*, not only to carry the fuel for the electric generating station of the line, but also to carry coal to Liverpool and Manchester, thus providing for a large source of revenue, which I have not included in my estimates. This coal would be loaded at the collieries in special boxes to be hauled along the ropeway, and on reaching either terminus, the loaded box would be landed on to suitable horse-tipping vehicles, and conveyed direct to destination, there being thus no break of bulk from the colliery screens right to the consumer's cellars, an advantage I need hardly draw your attention to, to say nothing of the immense saving in handling.

As this ropeway developed it would be possible to arrange for other terminii in various parts of the town to facilitate collection and delivery, and, as regards Liverpool, it might be possible to make such arrangements with the Mersey Docks and Harbour Board, who are ever alive to any improvement for facilitating the handling of their immense traffic, to take branch ropeways from the terminus to various

quays and wharves on their estate, so that, for special traffic, the merchandise could be loaded direct from ship's side into the ropeway carriers and so save the cost of horse haulage, and, similarly, goods could be loaded directly from the ropeway into ship.

For the actual line of the ropeway I should propose a double line of high-class steel wire rope on each side of steel standards, spaced throughout at distances of 200 feet apart, or multiples of 200 feet, so as to have even spans.

The steel standards, 30 feet high, I would build up of old steel railway rails, weighing about 70 pounds per yard, which could be got very cheaply, and would lend themselves to a very good design of standard, mounted on concrete foundations, and suitably guyed on each side with wire guy ropes, so as to make each standard independent and self-supporting.

I would place a high signal tower at every five miles distance along the line, so placed that the signal man in charge would be able to see the ropeway for a distance of two-and-a-half miles on either side of him, so as to at once be able to see if anything went wrong, and telephone the nature and position of the fault to the nearest repair shed. These signal towers would be in telephonic communication with each other, and would also be provided with a powerful search light, for guarding the line when the loads were standing at night time; these search lights would be energised from storage cells in each tower, fed with current from the working lines during the day time.

There would be six of these signal towers on the line, each costing about £500.

There would also be four travelling inspection cars, one to go each way every day, provided with a driver and an inspector, so that the state of the ropeway would be under constant supervision. These cars would ordinarily travel like one of the ordinary loaded cars, but would be provided with special detaching apparatus for dismounting the car at any standard and remain suspended there, out of the way, to allow for any special inspection, and until required again, or, if necessary, transferred directly on to the return ropes, to save the necessity of making the complete journey.

The power station for generating the electric current would be placed about midway between Liverpool and Manchester, close to the collieries, say near St. Helens, Haydock or Tyldesley, where the coal could be procured direct from the pit mouth without extra cost. The current would be generated at a high voltage, and sent along the line to each end by a separate copper-feeding cable, and transformed down

at intervals to an ordinary low working tension of say 500 volts, and fed from the transformers, either direct or through secondary feeding cables, to the various sections of the carrying wire as required. The return current would be made by the second carrying wire, which could be earthed at intervals, as occasion offered, to reduce the resistance.

CARS REQUIRED FOR A CONTINUOUS 10 HOURS' SERVICE.

At a speed of 5 *miles an hour, for* 1200 *tons each way per diem.*

1 train of 1 motor car and 1 trailer despatched every 2 minutes carrying a net load of 6 tons.

∴ 1 car per minute, and to keep the ropeway fully lined with cars so as to ensure the arrival of one train (of 2 cars) every two minutes, we must have on the ropeway between Liverpool and Manchester (say) 35 miles :—

$7 \times 60 = 420$ cars on each line up and down	...	= 840 cars
Allow an average of 3 hours per car to discharge and load, equals a stock at each terminus of $60 \times 3 \times 2$, say 360 cars at the two terminii (180 at each end)...		= 360
(half to be motor cars and half trailing cars) ...		= 1200 cars

Carrying 1200 tons of goods each way per diem.

The weight of the cars would average about 2 tons for a motor and trailer with their connecting rod, carrying 6 tons net load, so that the proportion of paying load to dead load would be about 3 to 1 in favour of the former, or say 75 per cent. of paying load to total load carried, a result which it need hardly be added could be obtained from no other system of transport.

Regarding the cost of working such a ropeway as I have described, I propose to take as my basis some figures kindly given me by Mr. S. B. Cottrell, the well-known engineer of the Liverpool Overhead Railway, which, as you are all aware, is worked by electric traction on the centre third-rail system.

Mr. Cottrell tells me that for the half-year ending 30th June, 1897, their total expenditure per train mile worked out to 15·03 pence, whilst the actual locomotive expenditure was only 3·42 pence.

As the weight of a train is 40 tons gross, you will see that the locomotive expenditure totals up to ·09 penny per ton mile, and the total expenditure ·38 penny per ton mile. These figures are very interesting and show what a wonderfully economical motive power electricity is,

when properly managed and equipped with the latest improvements in machinery.

I think you will agree with me that I shall be quite on the safe side in adopting the same cost per ton mile on our ropeway, as Mr. Cottrell has to maintain a proper staff for dealing with passenger traffic at 17 stations on his seven miles of railway, which of course would not be necessary for our line.

It may be argued that owing to this comparative shortness of the Liverpool line, and the correspondingly short distance the electric current has to travel from the generating station, that the basis is not a fair one, but against this I put the saving, already mentioned, of the greater cheapness of our power through the low cost of the fuel owing to our generating station being placed close to a colliery, and secondly the saving of the cost of a motor man and guard, whom the Liverpool line employ on each train, and who would not of course be required on our Ropeway.

I estimate the total cost for 35 miles of double line between Liverpool and Manchester, together with complete outfit, generating stations, safety bridges over highways, railways and canals, two terminii, land at each end, capitalised cost for easements, and all accessories, at £450,000.

For this I estimate the handling of 1000 tons of traffic each way per day, for 300 days per annum, or say a total of 600,000 tons per annum. Estimating a rate of 3s. 6d. per ton for the single journey, which is about one-half of the present railway rate, this will produce a gross revenue of £105,000.

The figures will therefore be as follows :—

Receipts per annum—	
600,000 tons at 3s. 6d. per ton	£105,000
Expenses per annum—	
Total working expenses, including depreciation, at ·38d. per ton mile, (say) 13½ pence per nett ton for the 35 miles *plus* 33 per cent. for the tare weight = 1s. 6d. per ton (say)	£45,000
Leaving a nett profit per annum of	£60,000

or sufficient for a dividend of 13⅓ per cent. on £450,000 without reckoning the extra profit on the carrying of the coal already mentioned, whilst by merely working two shifts of 10 hours each, instead of one, this profit would be nearly doubled, and could be still further increased by doubling the working speed to ten miles an hour.

The cost of working and depreciation comes out, you see, to about 43 per cent. of the gross receipts, which may be taken as a fair estimate, seeing that the average cost and working the whole of the main-line railways of this country, with their attendant high speeds, and heavy expenses, is only about 55 per cent. of expenses to receipts.

APPENDIX I.

INSTEAD of employing one carrying rope, as is usual, extending the whole length of the ropeway, entailing the use of a rope sufficiently strong to bear the strain of the total aggregate load that may be on the whole length of ropeway at any one time, a separate rope for each span is provided.

The ends of each adjacent rope pass over guides at each post, one end being attached to the post by a suitable tightener and spring, the guides leading the ends of the ropes downwards and backwards, out of the way of the carrier bucket and load.

The connection from one rope to another is made by means of a special rocking rail, which makes a good and smooth pathway for the carrier wheels from rope to rope, whilst the spring on the approach end of the rope draws up this rope and causes the catenary curve to flatten at each post as the load advances towards it, thus lessening the gradient by as much as one-half, with correspondingly less strain on the haulage power, the further advantages of this subdivision of the ropeway being as follows :—

(*a*) A much lighter carrying rope may be used, as it need only be strong enough to carry the strain due to the greatest load that can come on one span at a time.

(*b*) A much flatter catenary curve may be obtained, as a larger tension can be put upon the carrying rope without unduly straining.

(*c*) Should any part of the carrying rope get worn or broken it will be only necessary to replace the rope of the one defective span, instead of, as at present, having to renew the whole rope.

(*d*) Curves can be readily made, without the necessity of special angle stations as at present required.

(*e*) "Turnouts" or "pass-byes" can be taken from any post, it being only necessary to substitute a switching rail for the ordinary rocking rail at the post.

(*f*) Much larger individual loads can be carried on the single rope, and in case of extra large loads of say three to five tons, the weight can be divided on two ropes (one rope vertically underneath the other), as shown in the accompanying photograph.

(*g*) Each post and its attachments being all self-contained, excepting the guy ropes, the ropeway can be readily removed about from place to place, thus forming a "Portable Ropeway."

(*h*) The separate ropes being insulated from each other, an absolutely automatic block system of electric traction is at once provided.

(*k*) The ropes can be readily turned around from time to time, to ensure equal wear all round them.

APPENDIX II.

SINCE the author made up these estimates, Mr. Walter F. Jones, of Messrs. P. R. Jackson and Co., Ltd., of Salford, has been good enough to give him the benefit of his experience, and to go thoroughly into the details of the cost of the electrical equipment, and cost of working, and the author thinks he cannot do better than give Mr. Jones' report in full, just as he sent it, as it tersely sums up the whole situation :—

GENERAL PARTICULARS.

"We understand that the Ropeway is to be capable of conveying "1,000 tons of goods each way in ten hours, two tons being in each "car; the length of the line will be 35 miles; the speed adopted 5 "per hour; the posts will be 200 feet apart, and the cars will be "rigidly coupled in pairs, at a distance of 100 feet, so that the gradient "of the rope deflection will be ineffective."

NUMBER OF CARS REQUIRED.

"One train of two cars will be dispatched each way every two minutes. "This is equivalent to sending 1,200 tons of goods each way, and "allows a margin for stoppages. The trains will be 293 yards apart, "so that there will be 400 on the ropeway at once. The trains will "have to remain three hours at each end for loading and unloading, "and, in order that the line may be worked continuously, 90 trains "will always be at each end. This makes a total of 600 trains, or "1,200 cars.

POWER REQUIRED PER CAR.

"The gross weight of each train, including cars, tie rods, and goods, "will be, say, 7 tons. Allowing 50 pounds rolling friction per ton, "then each train requires 4·66 H.P. to move it, and with worm gear "of 80 per cent. and a motor of 86 per cent. efficiency, 5,070 watts will "be required at the motor, say 5,000.

DESCRIPTION OF ELECTRICAL SYSTEM PROPOSED.

"We propose to use a direct-current system, and the general arrange-"ment upon which we have based our calculations is shown in the "diagram, which we now send you. We should generate the whole "of the current at a point at the middle of the line, and supply it "to the trains, both direct from the generating station and also "through transformer stations, situated at intervals along the line.

"We should divide the line into seven sections, A B C D E F and "G, of five miles each. The central station, D, we should supply "direct from the generating station at an electrical pressure of 500 "volts, but the other sections would have current sent to their "motor transformers at an electrical pressure of 3,000 volts.

"We have arranged the feeders to the motor transformers so that "300 volts will be lost in each case in transmission, and therefore the "motor transformers will work at a pressure of 2,700 volts. The "500 volt current will be distributed to the cars by means of the 61/11 "S.W.G. distributing main shown on the plan, which will be con-"nected at the proper intervals to the rocking rail switch arrange-"ments, and so to the $1\frac{1}{2}$-inch steel carrying ropes, and the return "current will pass through the 2-inch ropes. The loss in electrical "pressure, in the distributing main, and return conductors, at the "furthest end of any section, with a full number of trains on the "line, will be 50 volts, and we should wind the motors to give a speed "of 5 miles per hour, at, say, 475 volts. With a variation in the "electrical pressure of 25 volts, each side of this, the speed would "vary from $4\frac{3}{4}$ to $5\frac{1}{4}$ miles per hour, depending upon the position of "the train on the section.

"Although we have drawn up our scheme with a direct current "system, of moderate electrical pressure, we should be quite prepared "to carry out the scheme with alternating current plant of very much "higher electrical pressure, say 10,000 volts; but, owing to the insula-"tion difficulties in the latter, we are of opinion that the direct "current plant would probably prove more reliable in working.

EFFICIENCY OF DIRECT CURRENT SCHEME.

"The work done in actually moving the cars, without taking into "account gearing or motors, is 1,960 H.P., and the Indicated H.P. "required at the generating station is 4,105, showing an efficiency of "47½ per cent. The efficiency of electrical transmission in the "motor transformers and conductors is 73½ per cent.

PLANT INCLUDED IN OUR ESTIMATE.

"*Equipment for* 600 *Motor Cars.*
"*Rocking Rails, &c.*
"*Cables, &c.*
"*Transformer Houses.*
"*Generating Station.*

"The approximate cost of supplying and erecting the whole of the "above will be £320,000.

"The above price does not include the cars or tie rods between the "cars, but it includes fitting the motors, gearing, and switches, to "the motor cars. A saving of, say, £50,000 could be effected in the "primary circuit by using an alternating current at an electrical "pressure of 10,000 volts, with suitable transformers, and if the "three-phase alternating system were adopted, with an electrical "pressure of 10,000 volts in the primary circuit, and the motor "transformers dispensed with, a further saving of £15,000 to "£20,000 could be made, making the cost of the electrical instal-"lation some £250,000.

"*Cost of Working.*—The cost of supplying power, and maintaining "the whole of the electrical equipment in working order per "annum will be approximately as follows :—

"Coal for 4,000 indicated horse power for (say) "4000 hours per annum at 1·2 pounds per indicated "horse power per hour equals 8,600 tons (say 9,000 "tons) at 4s. per ton	£1,800
"Oil, waste, and sundries	1,340
"Repairs	3,000
"Depreciation on (say) £250,000 at 5%	12,500
"Labour and Management	2,532
	£21,172

"*Cost per ton of Goods conveyed :—*

"730,000 tons of goods could be conveyed per "annum, working 365 days, and conveying 1000 "tons each way per day.

"The cost of supplying power and keeping the electrical plant "in repair will therefore be :—

$$\frac{£21,172 \times 240}{730,000 \text{ tons}} = 7\text{d. per ton.}"$$

NOTES BY THE AUTHOR ON MR. JONES' FIGURES.

Mr. Jones' figures for the cost of the Electric Installation are greater than estimated by the author, but, on the other hand, Mr. Jones' estimates for the cost of working are less than the author's, so that the practical result comes out nearly the same.

Taking Mr. Jones' figure of 7d. per ton for the cost of haulage from one end of the line to the other, and adding 3d. per ton for the terminal expenses at each end (which is a very liberal estimate, seeing there is no handling) makes the total cost 1s. 1d. per ton.

The figures will therefore be as follows :—

Receipts per annum—

730,000 tons at 3s. 6d. per ton £127,750

Expenses—

Haulage ... at 7d. per ton
Terminal expenses at 6d. per ton

13d. per ton

730,000 tons at 13d. per ton ... £39,544
Add 10 per cent. depreciation on Ropeway
(say) £200,000 ... ... 20,000 = 59,544

Nett profit per annum £68,206

or sufficient to pay a dividend of $10\frac{1}{2}$ per cent. on a capital of £650,000.

In conclusion, the author trusts that he has been sufficiently explicit, and that the scheme he has attempted to describe will be deemed worthy of consideration by the Members of the Liverpool Engineering Society. And although the description and figures relate especially to a ropeway between Liverpool and Manchester, it will be seen that such a system would be readily applicable to all cases where it is required to cheaply and expeditiously transport materials or even passengers from place to place, whilst its general utility for use in mines, quarries and works generally, appears to the author at all events very apparent.

DISCUSSION.

Mr. Coard S. Pain said—This paper is extremely interesting at this time, having regard to the revival of proposals for the more convenient and cheaper method of conveying goods between Liverpool and Manchester than exists at present. I think ordinary tramways have been too easily disposed of on the ground of the difficulty in clearing the groove in the rail from accumulations of dirt, but the removal of such accumulations is not an insuperable difficulty.

I also think the author has overlooked in his estimates the very important question of easements, which would certainly have to be paid for the right to convey goods across private property in this country.

In Mr. Holt's plateway scheme, with which I have been connected, one of the special features was the power to take goods off the wagons at any point, and draw them by horses to their destination. In the author's scheme no such convenient feature existed, and it would seem difficult to provide them.

I would like to know whether there would not be a risk of short circuiting in the event of some foreign substance, such as straw or wood, lodging between the rocking bar and the rope supposed to be out of contact.

Mr. J. W. C. Haldane said—The system proposed by the author has, no doubt, good and interesting features, but these will have to be developed in practice before much can be done with it. The ropeway system is one which has done, and is still performing, valuable service in various parts of the world, and especially in those of an otherwise inaccessible nature, but it remains to be seen whether as an ordinary goods transportation agency it can compete successfully with existing methods, or even with those now under consideration.

Mr. S. B. Cottrell said—I must congratulate the author on his able and interesting paper, but, in my opinion, the author's scheme will not overcome the present problem affecting Liverpool and Manchester, viz. :—"The cheapening of the transference of goods between the two "points, and without breaking bulk."

Aërial ropeways have, however, undoubtedly proved themselves extremely useful in mountainous districts and elsewhere, in mining and colliery operations.

Mr. J. Walwyn White, in reply, said—In reply to Mr. Pain, the

difficulties I mentioned in my paper as to keeping the grooves of ordinary street tramways clean, were not by any means over-estimated. It was a real difficulty, and a very small amount of dirt in the groove, or on the top tables of the rail, at once doubled the tractive effort necessary to haul a given load along.

As to the question of easements, that is, perhaps, a question more suited for an estate agent than myself to answer, but there is no doubt that the cost of easements for a ropeway, which only requires to touch the ground for a few square feet every 70 yards or so, would be vastly less than the cost of buying a continuous strip of land 30 feet wide or so, all along the line, which a light railway would necessitate, even if built on the narrow gauge suggested by Mr. Calthrop.

I do not think there would be the slightest difficulty in the short-circuiting as suggested by Mr. Pain. The working current I propose to use would only be at 500 volts pressure, and there is no difficulty with the insulation at this E.M.F. The feeding cables would, of course, be at much higher pressure, but as they would be carried, stretched from standard to standard, sufficiently far from any of the carrying ropes, and supported on double oil insulators, there would be little probability of any danger.

I am obliged to Mr. Haldane for describing the existing ropeways in Spain, crossing over mountains and valleys, but I think Mr. Haldane will agree with me that after all these ropeways are very much handicapped in their usefulness by their limited capacity for handling any weight of material. I understand the individual loads rarely exceed 10 cwts., and often enough are not even half this, and I know of one ropeway where they have six individual lines each way, making twelve lines of wire rope in all, so that they can get the requisite quantity of ore down from the mines, some thousand tons or so per diem, whilst with such a system as I recommend, one line of ropeway each way would be more than sufficient, to say nothing of the further saving made in handling large individual loads of (say) 2 to 5 tons each.

As to Mr. Cottrell's objection as to the difficulty of loading different goods in one vehicle, there would be no more trouble with this than on an ordinary railway, but I may say at once, that as there would be very much more traffic of large bulk goods always available than the ropeway could conveniently handle even with 5-ton individual loads, I would only accept full loads, in exactly the same way as the present main line railways will only accept minimum loads of 4 tons and upwards, where their mineral and other special rates were to apply.

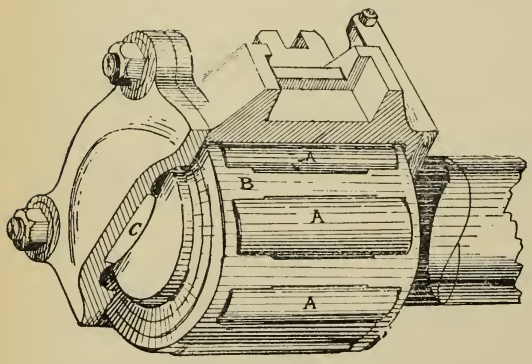
I regret if I have not explained sufficiently clearly how readily turnouts could be made from the main line of ropeway, at any given point. There is no question that turnouts or switches could be taken off from any standard by merely substituting properly curved and lengthened rocking rails for the ordinary ones.

I think the difficulties that Mr. Cottrell anticipated with the working of the rocking rails are more imaginary than real, and are only a question for proper arrangement of detail in making the designs. I would suggest having them made of manganese bronze, or other similar substance, which is very tough and does not corrode easily, or set up galvanic action with the wire rope.

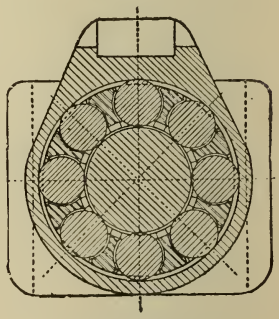
I quite agree with the remarks as to the use of street tramways. There would be no difficulty whatever as to the stoppages at different mills and factories *en route.* These could be supplied from separate shunts taken off as required from the main ropeway, in the manner I have explained to Mr. Cottrell.

At the same time, I may add, that as there would always be more than enough of *through* traffic from one terminus to the other, it would not be necessary to make provision for intermediate traffic, although there would be no difficulty in doing so.

With regard to the question of roller friction, I would propose to use some form of roller bearings, to reduce this friction as much as possible, and as far as I have seen up to the present, the best form of such bearings is that made by the Roller Bearings Company, of London, as shown, where A A A represents the bearing rollers, which revolve



SIDE VIEW.



CROSS SECTION.

around the axle, and are prevented from touching, or rubbing against each other, by the loose cage B, which is free to revolve around the axle along with the rollers, and thus save all rubbing friction. The

Roller Bearings Company inform me that by the use of these bearings the coefficient of friction on a level railway is reduced to 3 pounds per ton of load, and I think that on a properly constructed ropeway the friction would be very little more than this.

Besides, at the low speeds I propose to run, there would be practically none of the retardation, and air resistance such as comes into existence on a main line railway, at the high speeds now in vogue, and which in fact is one of the factors which prevent the great railways carrying goods at the ideal inclusive charge of 1d. per ton per mile, but which I think this ropeway, with proper management, could eventually accomplish.

With regard to the point as to the foundations, that was undoubtedly an important one, but I have fully allowed for this in my estimates. I understand there is good sound rock outcropping along a large proportion of the route, which would make excellent foundations, and if we came to any bog land, the ropeway line was so flexible (by the use of the curved rocking rails I have already described), that we could easily take the line around it, instead of over it, if we found any difficulty with the foundations.

A very pertinent remark was made to the effect that 3-ton loads had not yet been seen on a ropeway, but I trust the time will not be very long before we shall see 5-ton loads on a ropeway, by using this system of dividing the loads on two ropes, and using separate ropes for every span, such as I have attempted to describe.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

SIXTH MEETING, 19TH JANUARY, 1898.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,

PRESIDENT, IN THE CHAIR.

SHALLOW DRAUGHT STEAMERS.

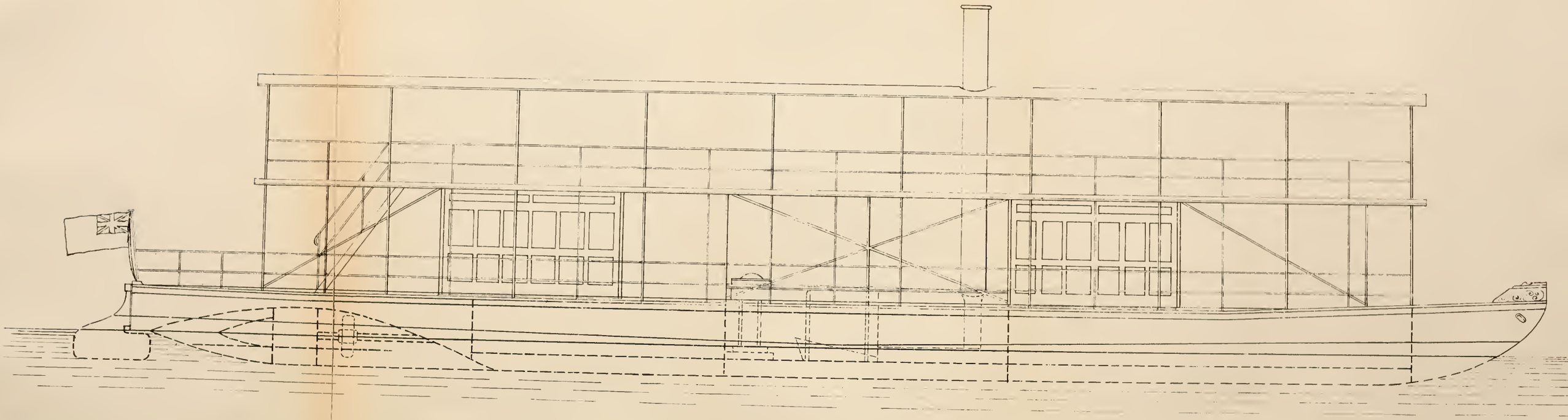
By SEYMOUR B. TRITTON, M. Inst. C.E., M.I.N.A.

IN contemplating the subject of this paper, the author is met at the outset by the question :—What may be considered a shallow draught steamer? He has decided to include, in this category, steamers with a draught varying from 60 inches down to 12 inches, which he thinks will be considered a sufficiently wide margin. He would point out, however, that the steamers more especially alluded to in this paper are such as are employed in river navigation, and of draught intermediate between the extreme limits mentioned, and especially designed for ferry traffic, passenger, and light cargo and survey purposes.

The author proposes to, at first, consider the different types of vessels most suitable for light draught services, to mention some details of the construction of the hull and engines of these vessels, and then to give a brief description of some of them which have come under his personal supervision and that of his firm, and which are illustrated by the drawings, models and photographs now placed before this meeting.

ERS.—

George Read & Co Ltd



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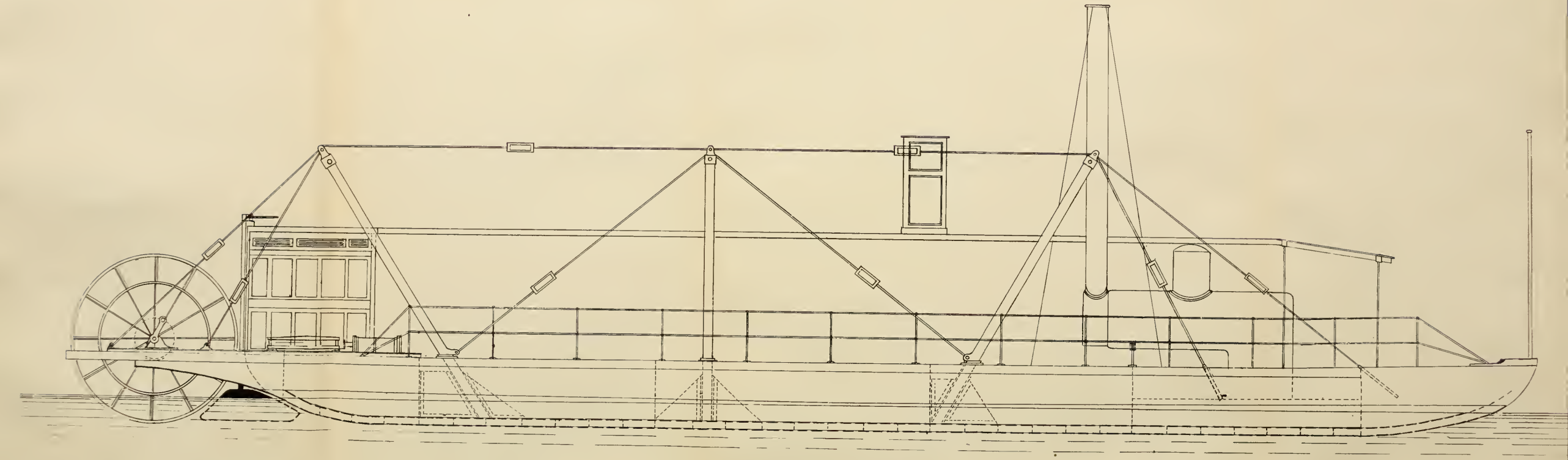
Shallow Draught Steamers.— *Seymour B. Tritton, M. Inst. C.E., M.I.N.A.*

Plate VI.



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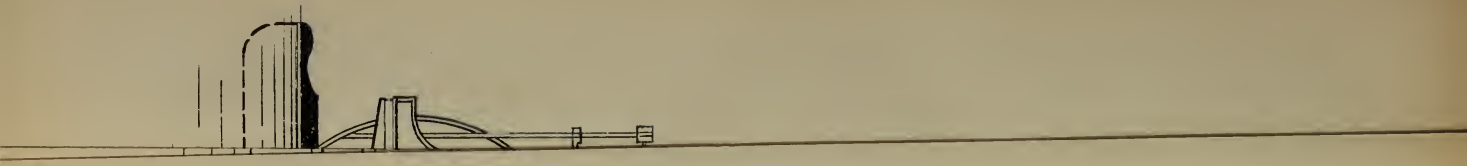
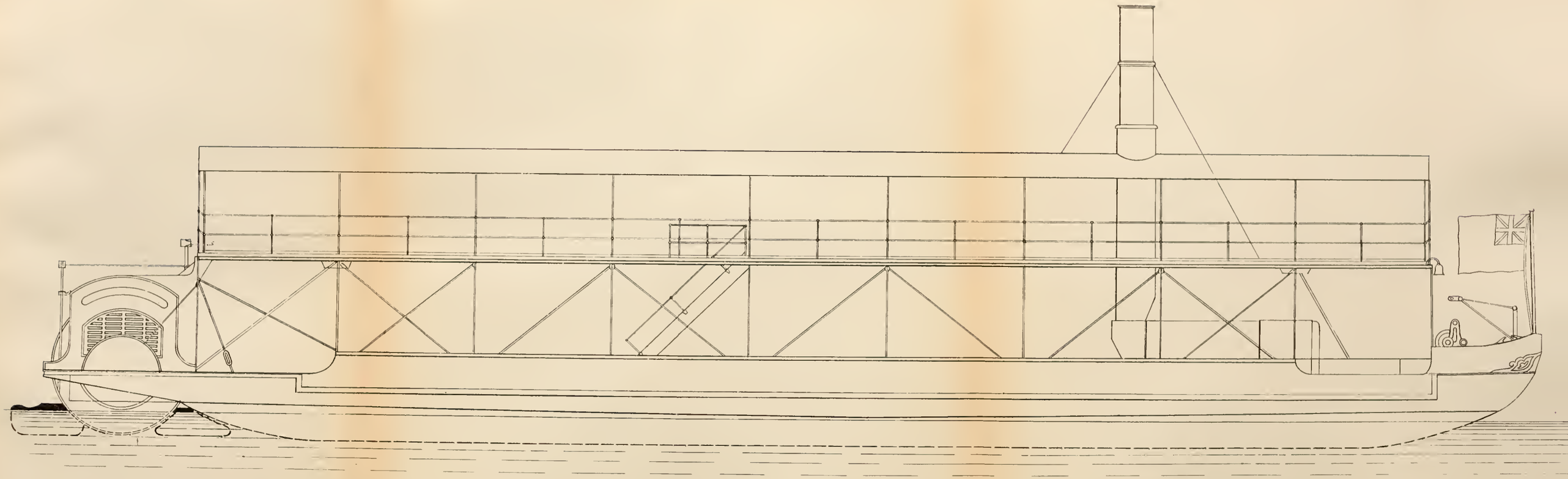


Shallow Draught Steamers.— *Seymour B. Tritton, M. Inst. C.E., M.I.N.A.*

Plate VII.



George Reed & Co Lithographers, 61 Stanley Street Liverpool.

The various types of vessels most suitable for this class of work may be divided into the following :—

(1) The stern-wheel steamer.

(2) The side-wheel steamer.

(3) The screw steamer of special form.

There are also light draught steamers driven by jet propulsion, and screw steamers propelled by the "Parson's steam turbine." The former method of propulsion has been more exclusively used in our steam lifeboats and hardly comes within the scope of this paper, and the latter is best known in the now famous torpedo boat "Turbinia." The features of this remarkable vessel, and her means of propulsion, have been so recently described in engineering journals, that the author will not occupy further time with any details and description of her, but the practical success of the direct rotary motion applied to the screw shafts, in place of the usual recriprocating motion, admits of a great reduction in weight throughout the machinery department. The system is one especially adapted for use in light draught vessels, and the author believes that its extensive employment for this purpose is only a matter of time and experience. As an instance of this the author has here a design for shallow draught screw steamer by the Parson's Turbine Co., in which it is calculated that a speed of over 30 miles per hour can be obtained on a draught of only 2 feet 6 inches.

With regard to these various types, the stern-wheeler has many advantages which fit her for very light draught work. The system by which the heavy weights of the engines and the boiler are distributed at the extreme ends of the vessels, and the use of truss and tie rods enables the depth of the hull to be considerably reduced, and also enables the designer to use his material to a considerable extent in tension, thus reducing the weight throughout.

A stern-wheeler has also been found in practice to have less slip than a side-wheeler. This is probably due to the action of the "following wave."

The floats of the paddle wheel work (or should work, in properly designed vessels) in this wave, the particles of which are actually in motion in the same direction as that in which the ship is going.

The stern-wheeler has no projecting paddle boxes amidships, so she can more readily navigate narrow channels; it is found, also, that this type of vessel can be more easily got off a sandbank that a side-wheeler when aground, owing probably to the paddle wheel being at the stern, and thus able to operate in comparatively deep water whilst the forward part is fast.

On the other hand, when the question of speed is of importance, it is difficult to give lines to a stern-wheeler for fast driving without unduly increasing the length, and heavy loads amidships may prove disastrous, whilst the steering of the stern-wheeler, in spite of two or three rudders, is often unsatisfactory. This point, however, will be referred to hereafter.

The side-wheel paddle steamer is so well known as to need little comment on the author's part, but for specially light draught work the paddle steamer has been, he believes, more generally adopted than the screw, and in most cases it has proved more efficient.

With the paddle wheel, the requisite area of float can nearly always be obtained by increasing the breadth of the float, whilst the screw propeller—with certain exceptions referred to hereafter—must be wholly immersed to obtain its full duty. Another feature of the paddle boat for ferry purposes, is, that it can be stopped and moved astern, in a very short space, the paddles acting as an efficient brake, an important consideration in foggy weather and crowded traffic; whilst if the engines are made to drive each wheel independently, the paddle steamer is very easily handled.

On the other hand, the cost of a paddle steamer is greater than a screw steamer of equal size and power, and the upkeep is undoubtedly more costly, whilst the paddle boxes are constantly getting damaged against landing stages, &c.

The weight of machinery per indicated horse-power can be made less in screw engines than in paddle engines, as, although 50 to 54 revolutions are now not unusual speed for the latter engines, the screw engine can naturally be designed more readily for a higher piston speed than a paddle engine.

With regard to the screw steamer (the author would remind you that he is always referring to light draught craft) the difficulty, as already mentioned, is to obtain the requisite diameter and area for the screw, whilst at the same time keeping it sufficiently immersed to become effective. For this reason, and on account of the tendency to set down by the stern at full speed, the screw boat has not hitherto found much favour for very light draught work. The difficulties mentioned have, however, been practically overcome by Messrs. Thornycroft and Co. with their patent screw turbine or guide-blade propeller revolving in air-tight channels, or spoon-shaped tunnels, forming part of the hull of the vessel. Referring to Plate V., you will observe that the bottom of the vessel is curved upwards at the stern in a fore and aft direction, this curve being the fullest where the propeller is placed.

It will also be seen that the waterline of the vessel is actually in the same horizontal plane, in this case, as the centre of the shaft; in other words, the propeller is half out of water. As soon as the vessel commences to move, the air is driven out of this spoon-shaped aperture in the stern, and the water rises in it, which has the effect of wholly immersing the propeller. Photographs Nos. 2A and 2B show the stern of such a vessel and will make the arrangement clear, and the author may mention that he has had very satisfactory results from this type of vessel. Messrs. Yarrow have also recently constructed some light draught gunboats on the same principle, fitted with the ordinary type of propeller, in which the water is actually raised some two feet above its normal surface. The advantages of a screw boat of this type are obvious, as the propeller is working in a head of water although only then at rest it is half immersed, or in other words a propeller of double the normal diameter due to the draught can be used.

Another special form of steamer which will be familiar to the members of this Society, is the screw vessel fitted with four screws, two at the bow and two at the stern. Vessels of this class have proved very handy to ferry traffic, but the system is not one from which a high speed can be readily obtained, especially on a light draught work, the Wallasey steamers "Crocus" and "Snowdrop" are examples of this class of vessel; a model of them is on the table for inspection.

Having now suggested some of the advantages and disadvantages of each type of vessel for light draught, river and ferry work, the author would mention a few points in construction which have come under his observation.

As the general construction of the stern-wheel steamer will be familiar to the members of this Society, the author will only refer briefly to it. The general principle is that already mentioned, of placing the comparatively heavy weights of engines and boilers at the extremities of the vessel, and trussing the hull to support them. Referring to Plate VI. (which shows a stern-wheeler of the most simple form) it will be observed that the weight of the engines and boilers is at the ends, and the king posts and tie rods supporting them and the ends of the vessel will be seen. It is the usual practice to attach the king posts to the shell or near the shell of the vessel, but where special rigidity and stiffness is required, the author has adopted a modification of this form of construction. Here, two lattice girders run from stem to stern about equi-distant from the centre line of the vessel and the shell, and upon the steel deck are stepped in

suitable sockets light king posts of T iron, the strains from these posts being transmitted to the girder below. The frames of the vessel are carried round to meet the upper deck beams. On the under-side of these beams (and attached to them) fore and aft tie rods of T steel are run, the ends of these tie rods are carried down to an adjustable connection to the girder again at the fore and aft ends. Further trussing, if necessary, is supplied as shown. This plan, though slightly heavier than the ordinary method, makes a very stiff vessel, and the rods, &c., being all in board, do not get damaged against barges and piers. For tropical climates, side awnings fit very handily into the side of the upper deck or roof, and can be rolled down the side frames to protect the cargo in the rainy season. Photo No. 3 shows barge built on this plan, discharging jute.

Models and photographs of vessels built to these designs (which have proved very satisfactory) are placed before the meeting.

When skilled labour is not obtainable, it is sometimes necessary to send light draught steamers abroad, and to the interior, in sections, each section being completed and rivetted up in the builder's yard. A handy plan of construction in such a case is to make a deep water-tight floor, a convenient distance forward and aft of the divisional frame, as shown in the photographs.

When the section is placed in the water, the water of course finds its way through the bolt holes of the frame, but the section will float, owing to the water-tight floors or partial bulkheads referred to, and will only draw a few inches of water. It is then an easy matter for the bolts connecting the section to be put in place in shallow water, and the joints screwed up watertight. The water between the joint and the partial bulkhead is then pumped out, and the vessel is thus put together afloat without the risk and trouble of launching complete. The photographs Nos. 4, 5A, and 5B, show a stern-wheeler and screw tug built in this manner.

Another matter already referred to with regard to the stern-wheeler is the difficulty in obtaining satisfactory steering. Referring again to Plate VI. it will observed that the usual and most convenient position of the rudder is just under the counter, and it is usual to fit two, and, in some instances, three and four rudders coupled together as seen in plan, but not always with satisfactory results. The reason of this appears to be that the rudders are working in a disadvantageous position, as the water does not get freely to them. The paddle wheel is drawing the water away from the rudders, instead of forcing it against them. In the practical handling of stern-wheel steamers

abroad, the author has also noticed that vessels built in this way steered much better when going astern, or in other words, when the water was driven against the rudders. What is wanted, therefore, apparently, is a rudder astern of, instead of ahead of, the paddle wheel.

Plate VII. shows how this has been carried out. It will be observed that the stern of the vessel is built out with a box-like projection forming the engine seatings. This projection does not float on the water, as experience has shown that if allowed to do so, it will somewhat neutralize the good steering effects sought for. Abaft this projection is fixed the rudder, of large area, and the paddle wheel is divided into two, and driven by a special design of engine placed between the two wheels. A smaller rudder is placed ahead of the wheel in the usual position, which is chiefly useful when going astern. Photos. Nos. 1, and 6A to 6F, show some vessels of this kind and their machinery during construction and when completed, and a model is on the table.

On side-wheel paddle steamers of light draught, the author would point to two details, amongst others, that require attention. With a hull of necessarily light scantlings there is a tendency for the paddle-boxes and connections to "droop" and put the shafting out of line. This difficulty may be guarded against by working four or more deep web frames in way of the paddle brackets and shaft to the height of the upper deck and connecting them by specially strong upper deckbeams. Photo No. 7 shows a vessel under construction illustrating this.

Another difficulty, when diagonal engines are used, is the working loose of the engine seating. If this seating can be incorporated into the keelsons instead of being made a separate structure, the strains are more readily distributed over a larger area. Photo No. 8 shows this also.

With regard to the type of engines for light draught side-wheels steamer, some weight and space can be saved by the adoption of diagonal engines in which the bearings are reduced to three in number, and the crank shaft made rigid in the working parts. Photos Nos. 9A to 9C shows a set of engines of this type, and it will be observed that the space occupied athwart ship is very small.

In some designs weight and space is again saved by the type of engines in which the high-pressure cylinder is placed above the low-pressure cylinder and the cranks connected by a drag link. Photo No. 10 shows this type of engine, and it will be noticed that the shafting is reduced to a very simple form, whilst the bearings are only

two in number. It has the disadvantage, however, as compared with the first-mentioned type, that the high-pressure cylinder must generally come above deck, and more room is therefore required fore and aft.

Time does not permit the author to touch on the question of boilers, the weight of which is a considerable cause of trouble to the designer of light draught vessels. Undoubtedly the water tube boiler offers the greatest advantages in this direction, but its adoption, for other reasons—for foreign work especially—at present is in many cases inadvisable. Failing the water tube boiler the author's experience of the locomotive type of boiler for light draught vessels, if properly designed for the service it has to perform, is that it gives excellent results, whilst its comparatively light weight and good steaming capacities are inducements for its adoption.

Photo No. 11 shows a type of "underfired" multitubular boiler, which is not uncommon in America, and which, under special circumstances, was adopted in two vessels under the author's supervision. It would, however, only be suitable in vessels running in smooth waters. The weight of a pair of these boilers, which contained 1,200 square feet of heating surface, and 36 square feet of grate surface, was only 17 tons, which was considerably less than either the marine or locomotive type. It is interesting to observe that a water tube boiler of equal power of the "Destroyer" class could have been fitted for a weight of 8 tons if circumstances had permitted its adoption.

The author will now give briefly some examples of vessels of various types and draughts. He has selected examples which have for the most part come under his personal observation, and hopes they may prove of interest to the members of the Society. The speed (as is usual for river and inland navigation) in each case is given in statute miles per hour.

5 *feet draught.*—Model on the table. Side-wheel paddle steamers "John Herron" and "Pansy," built by Messrs. J. Scott & Co., Kinghorn, for the Wallasey Urban District Council. 160 feet by 27 feet by 10 feet 6 inches. Compound surface condensing engines. Gunboat type boilers. Natural draft. 1,250 passengers. Speed 14½ miles.

4 *feet draught.*—Model on the table. Side-wheel paddle steamers "Ruby" and "Pearl," built by Messrs. John Jones & Sons, Liverpool, for Eastham Ferry Co. 134 feet by 22 feet by 8 feet. Compound surface condensing engines. Marine type boiler. Natural draft. 750 passengers. Speed 12 miles.

3 *feet* 6 *inches draught.*—Model on the table. Twin screw steamer of special form for despatch service, built by Messrs. Thornycroft & Co., for the Bengal Nagpur Railway Co. 90 feet by 15 feet by 6 feet 9 inches. Compound surface condensing engines. Water-tube boiler and assisted draught; closed stokehold. Speed 15 miles an hour.

3 *feet draught.*—Model on the table. Side-wheel paddle steamer "Benares," built by Messrs. Bow, McLachlan & Co., of Paisley, for the Bengal and North Western Railway Co. 170 feet by 28 feet by 8 feet. Compound surface condensing engines. Marine boilers, natural and assisted; (induced) draught. 1,500 passengers. Speed 12 miles.

2 *feet* 6 *inches draught.*—Drawing on the table. Side-wheel paddle steamers "Rajahmundra" and "Kavar," built by Messrs. Bow, McLachlan & Co., for the Indian State Railways. 132 feet by 22 feet by 6 feet. Compound surface condensing engines, "underfired" boilers and assisted draught. Speed 13 miles.

Also design for a screw boat already referred to, driven by the Parson's steam turbine, 240 feet by 24 feet by 7 feet; estimated speed 31 miles per hour.

2 *feet draught.*—Model on the table. Stern-wheel steamers "Parbatti" and "Ayesha," built by Messrs. Bow, McLachlan & Co. of Paisley, for East Indian Railway. 110 feet by 22 feet by 4 feet 6 inches. Compound surface condensing engines, locomotive type boiler. Natural draught. Speed 12 miles.

1 *foot* 6 *inches draught.*—Model on the table. Stern-wheel steamers "Rani" and "Begam," built by Messrs. Alley, McLellan, of Glasgow, for same service and of same dimensions as above but with compound non-condensing engines, and other modifications.

12 *inches draught.*—Photo No. 12. Screw steamer with spoon stern and guide blade propellers, built by Messrs. Thornycroft & Co., for service in Brazil. Speed 13·8 miles per hour.

8 *inches draught.*—Drawing on the table. Stern-wheelers built by Messrs. Bow, McLachlan & Co., for South Africa. 71 feet by 16 feet by 2 feet 9 inches. Wheels driven by bevel gearing.

The problem of carrying a large number of passengers and cargo on a light draught may perhaps be met in some cases by means of a light draught barge towed by the light draught steamer. This method was carried out with a fair amount of success in certain services under the author's control in India, the barges being lashed alongside the steamer and not towed astern. On a crowded river and for a quick service—like that required on the Mersey, for instance—there are

obvious objections to this plan, but the author suggests it as one for discussion. The model and photos on the table show a barge designed for this purpose, and which will carry about 160 tons of cargo or passengers on a draught of 2 feet 6 inches.

In conclusion, the author desires to thank Sir A. M. Rendel & Son, the Hon. C. H. Parsons, and the Builders of the various steamers mentioned, for the loan of models, photos and other valuable assistance in obtaining data for this paper. He is fully aware that it is largely of a descriptive nature only, but hopes that it may be the means of producing a discussion of interest.

DISCUSSION.

Professor H. S. Hele-Shaw said—The author of this paper was not, I believe, originally a naval architect, but received a training as mechanical engineer, and his success in the design and construction of shallow draught steamers shows what it is possible to do by the application of sound mechanical knowledge when applied to a new development, such as the subject which he has treated to-night. I cannot help pointing out how also his paper illustrates the new branches of our profession which are being continually opened up, the particular one we are considering having become an important industry, and rendering trade and commerce possible over vast regions hitherto unexplored.

As to the actual construction of these vessels it seems almost incredible how such fragile shells could hold together at all, one most important reason being the admirable way in which the stresses and strains are distributed, thanks to the great increase in latter years of our knowledge of the statics of structures and their design. This knowledge, together with the greatly increased use of testing machines, no longer render it necessary to have a large quantity of material put into a structure to provide for the unknown.

I understand from the author that the tie rods are all of steel, and I am rather curious to know if with mild steel used for this purpose and subjected, no doubt, to severe forces, the author has had the same experience which I remember came under my notice some years ago of the use of mild steel in railway wagons. In this case the constant jarring and straining stretched the rods and necessitated a continual screwing up, the material yielding very much like a plastic material, and the result in the end was that the steel had to be replaced by wrought iron, which was of a tougher nature.

Coming to the question of propulsion. When I was visiting Messrs. Yarrow's yard at Poplar, London, the other day, with a party of students, we saw one or two shallow draught steamers being finished with a spoon-shaped recess in the stern for the propeller. It seemed difficult to understand how this could work satisfactorily, but I was assured that the results were exceedingly good. It occurs to me that if propellers will work in a recess of this kind, at one part of a ship, why is it not possible to increase their number and provide a series of such recesses in which propellors could work, thereby obtaining all the advantages of distributing the propulsion which has been found so advantageous in the case of the "Turbinia," which has no less than nine screw propellers in order to attain its high speed without undue loss of power.

Coming to the resistance of shallow draught steamers, we know that a ship in a canal experiences an enormous resistance, and the reason is not hard to understand since the body of the water, which has to be displaced, has to find its way through the narrow section left at the sides of the ship. It is not so easy to understand the great resistance caused to shallow draught steamers since there is a large expanse of water on either side to allow this displacing effect to take place in. The experiments on which I have recently been engaged concerning the flow of water show, however, that in all directions from the skin the water is thrown into a state of whirling or eddying motion at a little distance from it. This state of whirling motion, as well as the tendency of the water to pass underneath the ship, will, no doubt, greatly disturb the bottom, and it is hard to see how this effect can be counteracted by any means in shallow draught steamers at high speeds. The question as to what proportion these two causes bear to each other is a very important one, since it is possible to imagine an entirely different means of causing a submerged body, such as a ship, to move through the water to that universally adopted at present, which would not necessitate the displacement taking place underneath, whereas all attempts to diminish the skin friction of a ship in any marked degree have hitherto failed.

Mr. J. Reney Smith said—I would like to refer to the steering of these steamers. At the present time we are going into a specification where a vessel has to draw 16 inches of water carrying 40 tons, stern-wheel type, and she is going at a big speed, 10 knots, and the difficulty is to so arrange the rudder to get an effective result on that shallow draught. In the specification it is arranged when the river freezes to run the vessel on to the surface of the ice, and proper launching ways

are being arranged for with this idea. I do not know whether there is practically smooth ice only, but these to my mind are the principal difficulties in going into this question.

Another point is what the author considers is the best form of joint where you get the plates a full $\frac{1}{16}$-in. thick.

Mr. J. D. Young said—I am sure it is very refreshing for those who have, perhaps, too much to do with salt water to have the subject of river steamers before them.

There are a good many things that strike one in reading this paper, and Dr. Hele-Shaw has made some pertinent remarks. One question occurred to me, and that is: What may be considered a shallow draught steamer? I would suggest, from a designer's point of view, that it should be a steamer having a certain relation between draught and length; for instance, a launch about 20 feet long and 2 feet draught would not, perhaps, be called a shallow draught steamer. A vessel 200 feet long with the same draught must be placed in the category of shallow draught steamers on account of her proportions.

In the list of steamers which the author gives us we find proportions varying from 15 to 25 draught to length. The lowest, 15 times draught to length, is, perhaps, a proportion which is common in the Mercantile Marine.

It would be interesting, I think, to compare results of steamers classified in their relation of draught to beam. Apart from the water underneath them shallow draught steamers take more horse power in proportion to their tonnage than ordinary steamers. I suppose this may be largely accounted for by the wave phenomena attending their motion, and by the large proportion of wetted surface relatively to displacement.

I think it would not be fair to ask the author to go into more detail than he has done, because it only lies with the author of a paper like this to point out the main features of design, and in doing so in such a suggestive manner he has earned our best thanks.

Mr. M. T. Reade said—As regards stern-wheel propelled craft, I should like to ask the author as to the form of the stern. I notice that in the model exhibited the stern rounds up very suddenly. I should like to ask if that is an advantage in the case of a stern-wheeler to produce the right sort of wave to give effective propulsion?

The President, Mr. George Farren, said—Before I ask the author to reply, I would like to make one or two remarks. I am rather interested in shallow draught steamers, and I only wish my steamer was a little more shallow draughted than it is.

I have seen on the Nile a boat get aground very often, and steamers have to haul them off. I saw a steamer tugging at a Dahaboy that was aground for three or four hours, and it was at last given up by the captain, who said it was the will of Allah!

Another point about the waves in the case of steamers going into narrow channels. The water seems in some cases to rush to the steamer, and the question has been suggested to me that you must treat the steamer as a whole, and take the rush of the water past the boat as the point to be looked to.

Mr. S. B. Tritton, in reply, said—With regard to the observations of Dr. Hele-Shaw, the tie rods at the end of the stern-wheelers are usually made of steel, and I have never observed any great difficulty about their stretching, and when once the vessel has been properly adjusted, when afloat, they seldom require much alteration.

With regard to steaming these light draught vessels out to foreign countries, this has been successfully accomplished in some instances; but the very heavy insurance, the extra stiffening and protection required by the Board of Trade, and the very great risk involved, are not very favourable to this plan. It is usual (especially where ordinary shipwright labour is available) to erect vessels complete in the builder's yard in this country, marking each part carefully with distinctive marks and colours, and send out the frames, plates, &c., to be re-erected abroad. Where skilled labour is not available, and where the size of the vessels permits, they are built in sections as described in the paper.

Referring to the question of light draught vessels settling down and thus increasing their draught in very shallow water, this is undoubtedly troublesome when going at any speed, but it is difficult to get any exact data on this point, and as regards this and the boiling action of the water under the vessel, mentioned by Dr. Hele-Shaw, I have observed this on some occasions, and I think that it might be seen locally—at the Eastham Bar—when the shallow draught vessels on that service are passing over it. It is usual, however, when the water is lowest at the bar to stop the engines just before coming to it and allow the vessel to float over into deep water, thus avoiding the dragging action referred to.

Referring to certain questions concerning the form of stern of stern-wheelers, in my opinion it is more important to give the vessel an easy "run in" from the sides than up from the bottom. This is illustrated by some of the models before the meeting.

Referring again to some observations made by members taking

part in the discussion concerning the steering, I can only repeat what I have stated in the paper, and I believe that the design with the rudder abaft the wheels is the best solution of the problem. As a matter of detail, however, it is worth noting that the rudders are more efficient when the tail of the rudder is carried well above the water line.

Replying to Mr. Young's observations about the comparison of a light draught river steamer and that of a big cargo vessel, I may mention that the ordinary speed formulæ applicable to a sea-going vessel of what would be called light draught (say) 17 or 18 feet would not be nearly so reliable when applied to a vessel drawing 2 to 3 feet, I have noticed that in the formulæ $\frac{S^3 \times D^{\frac{2}{3}}}{C} =$ I.H.P. the constant C is considerably lower in a shallow river steamer than it would be in a light draught sea-going vessel for the same speed, and that the skin friction resistance is a more reliable guide in many ways.

I think I have now touched on most of the points raised in the discussion, and thank the members of the Society for the interest they have taken in the paper.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

SEVENTH MEETING—2ND FEBRUARY, 1898.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,

PRESIDENT, IN THE CHAIR.

EXPERIMENTS ON THE FLOW OF WATER.

By PROFESSOR H. S. HELE-SHAW, LL.D., M. Inst. C.E.

THE subject of the Flow of Water has been one of the greatest importance from the earliest times. The ancient aqueducts of Rome and Carthage, the irrigation work on the Euphrates, the success of early shipbuilders, all show the practical manner in which the properties of flowing water were turned to account in Naval Architecture and Engineering. Yet, until about 250 years ago, not even the most elementary laws were understood. Torricelli, in 1643, applying to fluids the mechanical laws of his master Galileo, found that a jet of water issued from a vessel with a velocity which varied as the square root of the head. This was quite contrary to the views of even the most eminent water engineers of that and previous times. It is not surprising that any idea of water behaving as if consisting of frictionless particles falling from the height of the

surface was likely to be thought of when we know how water really issues from a vessel, as shown by the annexed figures (Figs. 1 and 2).

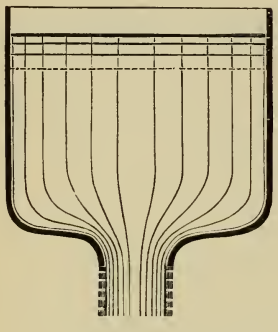


Fig. 1.

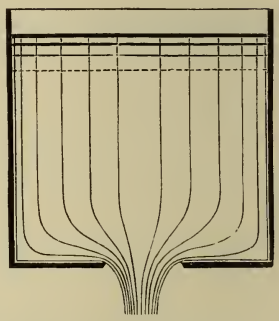


Fig. 2.

It was by Bernoulli, about 1730, or nearly 100 years later, that the first attempt was made to follow the motion of the fluid in detail by his stream line theory. This has been amply illustrated by beautiful experiments by the late William Froude. The stream line theory treats the fluid as moving in streams such as in the diagrams. When a narrow portion is reached these lines behave like soldiers passing through a defile, who have to change their formation. Hence, for the whole body to move at the some velocity as in the original wider channel, the speed at the narrow portion must be correspondingly increased, or, what is the same thing, for a given quantity to pass in a certain time at every point, the velocity at the narrow parts must be greater than at the wider parts. Now at first, the pressure might be thought to be the greatest at the narrow portion, but it is found that the contrary is the case, and this may be readily explained upon theoretical principles. Froude also investigated the flow of water round a ship's side, and showed that, given a fair form, the cross section had nothing to do with resistance. The surface friction and wave and eddy making are by him taken as the sole factors of resistance. This again is quite contrary to the idea of older Naval Architects, whose rules were based on the idea of ploughing out a channel of cross section equal to that of the ship.

These three examples serve to illustrate the difficulty of arriving by a process of tuition at real laws governing the flow of water. Perhaps I may be allowed to add yet another. In the diagram (Figs. 1 and 2)—

$$\frac{\text{Discharge from the 1st vessel}}{\text{Discharge from the 2nd vessel}} = \frac{\cdot 815}{\cdot 615} = 1\cdot 325$$

But $$\frac{\text{Loss of energy of 1st vessel}}{\text{Loss of energy to 2nd vessel}} = 10$$

If, however, the sharp edge in No. 2 is rounded—

$$\frac{\text{Discharge by No. 1}}{\text{Discharge by No. 2}} = \frac{\cdot 815}{\cdot 97} = \cdot 84$$

and Discharge by 2nd vessel is now 1·2 times that by 1st.

These facts have been arrived at by experiment and observation, and have been frequently verified, but the theoretical grounds for their truth are now clearly understood. They serve to illustrate the paradoxical and difficult nature of the subject of fluid motion, and the truth is that, although much progress has been made in the subject of Hydraulics, a great deal has yet to be learnt about the real nature of fluid motion. Nor is this difficulty hard to understand. We can follow the motion of a solid body, such as a wheel, as a whole, but it is quite otherwise with the individual particles of a fluid.

Now there are two methods of investigation which have been respectively called the Historical and Statistical. The former follows, or attempts to follow, the path and behaviour of individual particles, or a small group of particles; the latter treats the behaviour of the fluid as a whole, passing a given point or through a plane, and this is the method by which nearly all our hydraulic data have been arrived at. The latter includes work with current meters, notches, and towing experiments, where the general effect of the sides of the channel upon the flow, or of the water upon the speed of the ship, is to be observed. The former may be illustrated by the use of floats for current observations, and it is well known how erratic and uncertain their behaviour may be.

Another possible method, however, of historically observing the behaviour of flow is by means of stream lines, which offer the best mode of obtaining a mental picture of the behaviour of flowing water. I made many attempts to construct an apparatus that would exhibit on a screen by means of a lantern these stream lines to students, and at last hit upon a method which I propose to exhibit this evening

At the short notice I had, all I can do in this communication is to give you an account of, and exhibit, certain experiments based upon the introduction of air into the flowing water. An account of some of these experiments was given before the Institution of Naval

Architects, July, 1897, but the rest, which are of equal interest, I have since made.

No matter how complex the flow of water may be, unless some foreign substance is introduced, or there are vacuous spaces, there is nothing to indicate what is taking place. Colouring matter may be used at very low velocities, but for the purpose in view, in which reasonably high velocities were required, this is quite useless, as the colour immediately mixes with the body of the water. Foreign substances, such as sand and spermaceti were tried, but, apart from the general indistinctness of the stream lines, the sand accumulates in the places where eddies are formed and vitiates the results. The same may be said of most foreign substances. It was, however, discovered that in the narrow part of the entrance pipe in the lantern apparatus, where the velocity was greater and of course the pressure less, an induced current of air leaked in, and finely divided bubbles gave exactly what was required on the diagram.

A full account of the apparatus is to be found in the Proceedings of the Institution of Naval Architects, and in "Engineering" of July 16th, 1897, and "The Engineer" of August 13th.

The general questions which the experiments seemed to throw some light upon, may be classified under the two heads :—

(1) The nature of the lines of flow round bodies of various forms, and through pipes with the different obstructions usual in practice.

(2) The nature of the resistance commonly called "surface" or "skin" friction.

Fig, 3.

Fig. 4.

Figs. 3 and 4 show a rectangular body which is turned both sideways and endways to the stream, the water in the latter case appears to be

heaped up somewhat in front of the body, so as to form an artificial cut-water, and thus prevent the form of flow which is generally assumed to take place under the circumstances.

Figs. 5 and 6 show what may be taken as a ship, giving the cases of the rudder steady and hard over, and it will be noticed that in the latter case the effect of the rudder on the current is to produce a

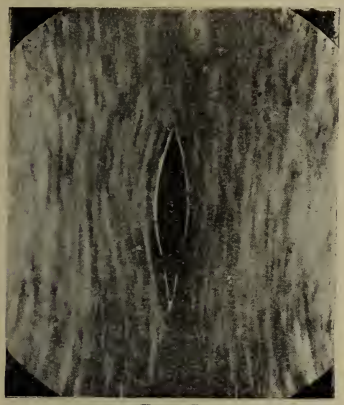


FIG. 5.

FIG. 6.

general set round the opposite side of the ship to that towards which the rudder is placed; *i.e.*, if the helm is hard aport, the rush of water takes place round the port side of the ship.

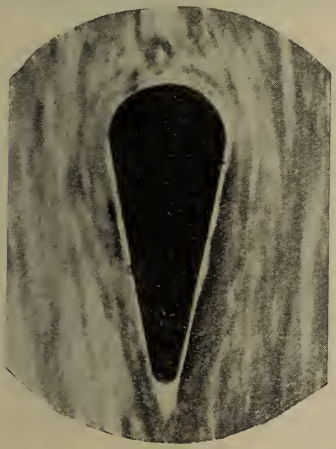


FIG. 7.

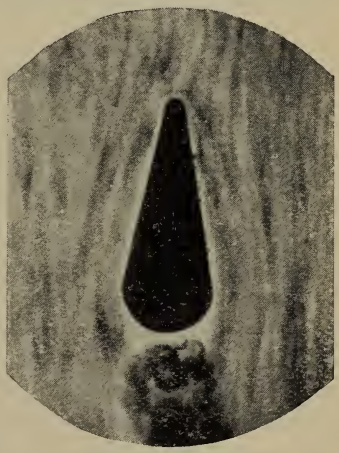


FIG. 8.

A series of examples illustrating the well known beneficial effect of a fine run aft, and the comparative unimportance of a blunt bow and entrance was then shown. Figs. 7 and 8 show clearly the comparative results obtained.

Fig. 7 shows clearly how little resistance is caused by a bluff bow, there being scarcely any eddies as a result of this. Fig 8, on the other hand, shows the same model reversed, and the eddying motion produced by the stern is obvious. Fig. 9 shows the clear border line for the case of a jet impinging on a surface of double convex form. Fig. 10 shows the same experiment with mucine injected into the water so as to obscure it, except where the thin film exists, and this film of clear water is seen to make its way into the general mass

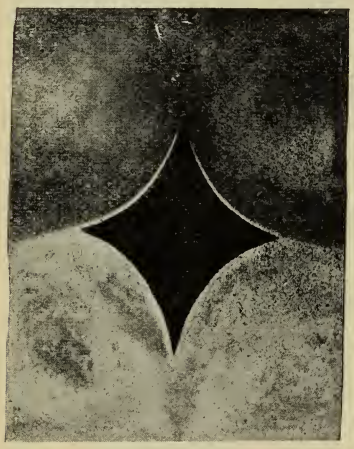


Fig. 9.

Fig. 10.

of the fluid, thus proving the phenomenon to really exist in the water and not to be merely the effect of refraction.

Now in all these examples it will be seen that there is a clear border line round the immersed body, and at that portion of the body which is in contact with the water in the case of the action of the jet, and this is an effect which is considered under the second head. In Fig. 6, which will be referred to at greater length later on, it will be noticed that the clear border passes beyond the limits of the body.

The natural question suggested at first was, whether this border was caused by refraction of light in passing through the parallel layers of the glass and water, and very careful means were taken to investigate this point; but this matter was completely set at rest by subsequent experiments, and need not be alluded to further.

The question arose as to what was the cause of this clear border which has different breadths at different points, the amount of which can be modified by varying the velocity of flow, which, of course, was quite invisible as long as the air was not admitted, the presence of

which the admission of coloured fluid or any finely divided solid bodies in the water did not reveal in any way to the eye?

To obtain an answer to this question the changes effected by rubbing the sides of pipes and obstructions with grease and by roughening the surfaces were first observed, and also the effect of injecting coloured liquid more or less suddenly into the flowing stream. In the latter case it was noticed that the colour seemed to pass first into the general body of the water, and linger last round the portion where the clear border line was shown.

The result of many observations and experiments has led the author to the conclusion that the clear border line represents a condition of parallel flow of layers of water past the skin of the obstacle, or the sides of a pipe, in which a state of shearing exists, while outside this, in the darker portion, the water is in a state of sinuous motion. The difference of the two appearances undoubtedly represented on the one hand the condition of water in which the mere viscosity came into play, resisting the shearing stress of the layers in passing over each other, and on the other hand to the breaking up of the water into eddying motion when the resistance was much greater.

It is well known that at low velocities the resistance of water varies directly as the speed, while at high velocities the resistance varies more nearly as the square of the speed, and Professor Osborne Reynolds has investigated the critical velocity at which this occurs, and has given calculations concerning the critical velocity, accompanied by an account of some beautiful experiments, which showed the sudden breaking up at the critical velocity of the stream in a glass tube, which had been flowing quite steadily until that critical velocity was reached. Now the water must have its velocity greatest in the middle of a channel, and zero at the sides. If this is the case it seems obvious that in no event can a whole body of water in the tube break up into sinuous motion; for, if the matter be thought out carefully, it is evident that, although it is possible to have one of the conditions by itself—viz., the condition of lower velocity and parallel flow—it is not possible to have the other condition by itself—viz., the condition of sinuous flow—and this leads irresistibly to the conclusion that at some point or other there must be a line of separation between the two. Professor Reynolds expresses his surprise at the suddenness with which the change took place between the two states of flow in the following words:—"I had not therefore considered the disturbances "except to try and diminish them as much as possible. I had expected "to see the eddies make their appearance as the velocity increased, at

"first in a slow and feeble manner, indicating that the water was but "slightly unstable. And it was a matter of surprise to me to see the "sudden force with which the eddies sprang into existence, showing a "highly unstable condition to have existed at the time the steady motion "broke down."

Now whereas Professor Reynolds was surprised at the suddenness in *time* at which the change of state took place when the velocity rose beyond a certain point, the foregoing experiments seem to show a suddenness in *position*, where the change of state occurs, which is even more startling.

The idea of lubricating the side of a ship by exuding some substance, usually mineral oil, has been frequently suggested; indeed, there have been many advocates of the use of air in this way. The idea in such cases has been to obviate the carrying along of a body of water with the ship. It seems clear that neither of these substances can be so applied, for if once the side of the ship or the inside of a pipe is wet, or causes water to adhere, the shearing action at this wetted surface must result, at certain speeds, in setting up eddying or sinuous motion in the surrounding water. This sinuous motion is capable of absorbing all the enormous power taken up by what is known as skin friction without any great mass of water being necessarily carried along bodily by the ship. It does not, however, follow that great improvements may not be made in the direction of reducing skin friction.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

EIGHTH MEETING—16TH FEBRUARY, 1898.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,
PRESIDENT, IN THE CHAIR.

Discussion upon Dr. H. S. HELE-SHAW's paper, entitled—

"EXPERIMENTS ON THE FLOW OF WATER,"

which was read at the meeting on the 2nd February, 1898.

Mr. M. T. READE said—It appears to me, on looking at the slides, that the water is moving at a greater equivalent speed than in practice is attainable in a boat. I measured one of the models and found it to be $\frac{5}{8}$-inch long, and assuming the speed of the water at $1\frac{1}{2}$ feet per second past the model, the equivalent speed of a boat 10 feet long would be about 20·8 feet per second, or a little over 12 knots an hour. A boat 10 feet long moving at 12 knots an hour is, of course, practically unattainable.

I should like the speeds of the models to be made to compare with the actual speeds of the vessels.

Mr. THOMAS DUNCANSON said—I have had some experience in the flow of water, but not in connection with marine work; but the same principles apply to the flow of water through pipes as apply to the case of marine propulsion. My remarks, therefore, may still have some bearing on the points brought before us.

In the first instance, I may say that the author is to be congratulated on his paper. He explains that his object, in the first place, was to

demonstrate the historical mode of treating the question, and, I think, he has achieved a complete success. Slides of this kind show exactly what does take place in practice, and for students they are almost invaluable.

With regard to the diagram (Figs. 1 and 2, p. 110,) as to the discharges from two vessels, and the difference in such discharges if the sharp edge of one vessel is rounded, I am hardly at one with the author. I think there is a case in which that statement would be correct, but as a general statement I think it is a little misleading. The degree of roundness has a very considerable effect on the amount of discharge.

I have had an opportunity of making some experiments on jets with sharp and rounded edges.

The following are the details of the experiments. They were carefully made with orifices exactly 1 inch in diameter, under a head of about 8 inches, and are correct to within one per cent.

Form of Orifice	Diameter of Orifice	Thickness of brass plate	Coefficient
Sharp edge	1 inch	$\frac{1}{16}$ inch	·615
Edge rounded to radius of $\frac{1}{16}$-inch ...	1 inch	$\frac{1}{8}$ inch	·737
Edge rounded to radius of $\frac{1}{8}$-inch ...	1 inch	$\frac{3}{16}$ inch	·831

My point is, that inasmuch as the statement is given that if an orifice is rounded a certain result is obtained, that result would only be obtained if the rounding is of very large extent, in fact having the form of the *venu contracta.*

With regard to the point upon which the author has asked us especially to speak, I have taken great interest in the slides showing the effects of the different shapes of bodies passing through water, and the point that struck me was that it was quite clear that we see along the edges of the various bodies clear spots, and we also see in the wakes of them clear spots. These spots are, of course, where there is no air. In the case of the wakes I do not suppose there is any parallel flow. Is one to assume that where there are clear spaces not in the wakes, there is necessarily parallel flow?

The author's method of investigation might possibly throw further light on the reason why the discharge of water through a

water main is so largely diminished when its surface becomes roughened by incrustation. In the formulæ $v = c \sqrt{r s}$, where r is the mean hydraulic depth, s the sine of the inclination, v the velocity, and c a coefficient, it is not unusual to find in a pipe 3 to 4 feet diameter c reduced from 110 with a clean pipe to 70 with an incrusted pipe. No doubt this effect is caused by the eddies produced by the irregularities on the surface; but the author's method would probably throw more light on the mode in which these eddies act.

I may say, in conclusion, that the author's paper has been very interesting and suggestive in many directions. He has, without dogmatising, indicated directions in which progress may be made, and I trust that on many occasions in the future as well as in the past we may find him breaking new ground for us in scientific engineering.

Mr. H. J. J. Ashton said—I should like to ask the author where the greatest velocity in these flows is, *i.e.*, whether on the concave or convex side; also whether the film of still water does not increase on the convex side as the flow decreases. I have found in a great many experiments that on the flow of water passing the concave of a river it forms an eddy and returns in the opposite direction; the line of demarkation being quite perceptible.

I should like to ask the author his opinion as to where the greatest velocity is?

Mr. Coard S. Pain said—The first point that occurs to me is that the conditions under which the experiments are conducted are at variance with the conditions which occur with a vessel at sea. My reason for thinking so is that a vessel at sea is not surrounded by any framework as in the experiment, though to what extent that affects the matter I am not quite prepared to say. Again, it seems to me that the injection of air, whilst extremely interesting, may have a very material effect upon the water currents. A vessel passing through air and water would be very different to a vessel passing through water alone.

The experiment is effected with a piece of metal fixed between two walls of glass representing a vessel. You, therefore, obviously lose the whole of the effect of the air above and the water under the vessel tending to raise it, &c. What did occur to me was that the effect produced on the screen must be very much like the effect produced by a torpedo in passing through the water.

I do not quite understand how a stream of water passing against

a stationary object can be exactly the same thing as a moving object passing through a quiescent body of water.

Mr. W. E. Mills said—One thing that has occurred to me is, that a great shock has been given to us, and to our generally received opinions, as to the proper form of the hull of a ship. The author shows this very remarkably in the two Figs. 7 and 8, where he draws attention to the fine run aft and the blunt bow. I think this is very remarkable. The old idea, as I understand it, in building a ship was to build a body which would cleave its way through the resistance caused by the water in the same way as a wedge enters a block of wood, and consequently the bow was made sharp. The early builders apparently neglected the form of the stern, and there is no doubt whatever that they concentrated their attention in the form of the bow. The author refers to this, but he shows us that a blunt bow is unimportant, but that a fine run aft has a very beneficial effect.

To take the latest examples of shipbuilding for high speed, I suppose the torpedo destroyers are, perhaps, the best examples, and there we find that the fine run aft is carried to an extreme pitch, and to that extent the designers of these craft are in accordance with the author's notions, but we do not find, on the other hand, that the bows are comparatively blunt, and it seems to me that one theory at any rate is apparently antagonistic to the other, unless the explanation is this, that a blunt bow does not offer the resistance to the passage of the boat through the water which it has generally been considered it does, but that the amount of resistance of a bow of given bluntness is less than has generally been thought, and if you have a fine run aft you may, to some extent, do away with the obstructive effect of a blunt bow. Does the author mean us to understand from Fig. 8 that the eddying motion at the stern is a drawback. It appears to me that this eddying motion is caused by the difficulty of the water in closing together after it has been parted. It is clear from Fig. 7 that that closing together takes place within a very short distance of the stern of the ship. In Fig. 8 that closure does not take place until the bottom of the figure, and I assume that that is considered a drawback in the design of the model ends, but surely that cannot be altogether a drawback unless it can be shown, and of that I am not quite clear, that the failure of the water to close in rapidly behind the ship tends to a retardation of the passage of the ship. If that is so of course my observations are beside the mark, but the point I am trying to make is this: Does the author wish us to understand that provided you have a sharp stern, and in consequence a quick

closure of the separated portion of water, it is unimportant whether your bow be sharp or otherwise. If that is so it seems a complete reversal of our ideas with regard to shipbuilding.

Perhaps we have never asked ourselves the question as to what has governed the designs of ships in obtaining a model which will offer the least resistance to water in its passage. Of course shipbuilders have many other questions to consider, but if they were to have the problem put before them as to what form of hull would achieve the greatest result in offering the least resistance in its passage through the water I should very much like to know whether the type of vessel we have been accustomed to see is the correct one.

Mr. Robert A. Sloan said—I have some diffidence in speaking on this subject, because I cannot speak with the confidence borne of specific experience to either of the points which the author has raised.

The author tells us, with his accustomed modesty, that the idea of introducing the air was purely accidental. No doubt that is so, but there are accidents and accidents, and observers and observers, and it is the mark of genius to grasp all the suggestiveness of a happy accident and turn it to full advantage.

The most important matter appears to be the existence of this white stream immediately adjacent to the obstacle. I confess that when I first heard of it, it interested me strongly, and though it is easy to be wise after the event, it almost seems to be what we might have anticipated,

It is well known, of course, in dealing with the friction of fluids, that if we drive one immersed flat surface past another close and parallel to it, there is a critical speed at which an abrupt change occurs in the law of the resistance, and the theory is that up to this critical speed the relative molecular motion is one of pure shear, and that after that a sort of sinuous motion is set up, the frictional resistance suddenly rising in a marked degree.

If, then, we have two layers of liquid sliding one over the other, the character and intensity of the frictional resistance depends upon the speed with which one slides over the other. If we consider a ship running at (say) 12 knots through water, it is natural to suppose that the layer which is in contact with the ship either travels with the speed of the ship or approximately so. The water (say) a foot away may for the present be taken to be at rest ; between this and the ship we must have layers in which the speed is progressively rising from zero to a maximum. The important point is to find out the way in which the speeds of the successive layers vary as we pass outward from the skin

of the ship. I do not know whether experimental research has been made in this direction, but it is one that would justify some research. In the case of the models shown to us the effect seems to be very clear. There must be a progressive decrease of velocity from the layer against the ship to that which is practically at rest. It would be interesting to discover at what difference in the relative speed of adjacent layers the change from sinuous to shearing motion occurs. This paper will give me a very much keener interest in anything of the kind in the future, and if it does that with all of us, it will achieve a very good object.

The President, Mr. George Farren, said—I submit to the members an exact and careful drawing of a piece of submerged material, which is copied exactly from Sir William White's book, which you will notice is slightly different from what we have seen to-night.

I would just draw attention to the fact that Sir E. J. Reed, Her Majesty's late Chief Constructor, and Sir W. H. White, Her Majesty's present Chief Constructor, both said that the introduction of the air into the flowing water, which was the invention of the author, might lead to serious consideration of some of the theories at present accepted, and especially in regard to skin friction of ships.

But I would point out that in considering those highly successful experiments, that though the author had approximated as closely as possible under the circumstances to the natural order of things yet his experiments necessarily differed somewhat therefrom, because in his experiments the models of vessels and other models which he exhibited were fixed, whereas a ship at anchor was not fixed but had a certain amount of play dependent on the length of her anchor chain.

And further, because in these experiments, in two directions, under pressure, there was no freedom of motion; while longitudinally the play of the current could be seen. In a ship at anchor in a smooth, strong current, however, there were two freedoms of motion—the vertical motion being the only motion cut off. But in the case of a ship at anchor in a rough sea she would have freedom of motion in three directions, the vertical motion being controlled by the varying length of the chain.

Dr. H. S. Hele-Shaw, in reply, said—In the first place, with regard to Mr. Reade's remark, I think I gave a velocity merely as a rough approximation, and I am not quite prepared to stand by its absolute accuracy because it is extremely difficult to measure the speeds at

various periods. They are, however, comparable—many of them—with those achieved in practice.

Mr. Duncanson's observations are extremely interesting and valuable.

With regard to the clear space question, it is, exactly as Mr. Sloane put it, a dynamic shadow. The effects are invisible if the air is not present. I say that next to the skin of the ship you get water at high pressure and low velocity, and the air will not go into it. The difficulty is to account, except on my supposition, for the fact of this clear cut line at which a change of something or other of the kind I suggest occurs. At a high velocity there is a clear cut sharp line of division between the one portion where the air will not enter, and the other portion where the air is mixed up with the flowing water.

With regard to Mr. Ashton's remarks, these diagrams do not pretend to represent the actual conditions of flow in a river where many things would be utterly different, one essential condition, viz., a free surface, being absent in my experiments. The general behaviour of the flow in a bend is that the lighter particles try to cut the corners because the heavier particles are thrown outward, and this is clearly shown in my diagrams.

Mr. Pain has made remarks which would be just criticism if I had claimed anything for these experiments in the nature of a generalisation on the behaviour of ships.

In the case of a ship we have a free surface, which causes the formation of waves, and where the conditions are in three dimensions of space instead of two, as in that of my experiments.

He also said that the motion of a body of water past a ship was not the same when a ship moves through the water at rest. This is to some extent true, but the difference is not so great as I think he imagines. I have been astonished to find from some of the greatest naval architects how far reaching is the stream line effect of a vessel moving through still water. I may say that I am making experiments now with a body pulled through the still water, and am photographing the results. I have not, however, drawn any conclusions concerning the general behaviour of a ship from my experiments, and this brings me to the remarks of Mr. Mills.

When I pointed out that the phenomena of the flow of water round an object are in accordance with well-known facts, I thought that the dictum of Froude,—that it was blunt tails more than blunt noses that affected the resistance,—was well known to everyone. All I have done is to make visible the cause of what the naval

architect well understands from actual results; to show, in fact, to the eye what men have arrived at from practical experience, and what I think is quite contrary to our natural view of the case where we should naturally place the sharp edge in front.

My experiments show the same general result as that given in Sir Wm. H. White's book, although I have used a restricted channel, but the pictures bear comparison with the drawing exhibited by the President and taken from that book.

I would like, however, to remark that mathematics has hitherto been unable to deal, or attempt to deal, with the question of resistance in channels.

I hope to bring before the meeting at some future period the results of a fresh research into this matter.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

NINTH MEETING—2ND MARCH, 1898.

GEORGE FARREN, J.P., M. INST. C.E., F.R.S.S.,
PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz.—The Right Hon. Lord CHARLES BERESFORD, C.B., M.P., and Sir WILLIAM H. WHITE, K.C.B., LL.D., F.R.S., as *Honorary Members;* Messrs. G. C. AITCHISON, CHARLES E. BUNCH and J. S. POOLEY, as *Members;* and Mr. W. T. BREMNER as an *Associate.*

ENGINEERING SURVEY WORK.

By J. H. T. TUDSBERY, D. Sc., M. Inst. C.E.

ALL survey work is related to Engineering, but the author asks consideration of that department only in which the scientific conditions and the precision of result aimed at call for the exercise of Engineering skill of a high order. Although every member of this Society may be well aware that the name "Engineer" is only properly applied to one who is peculiarly conversant with and skilled in certain of the arts—we can hardly fail at times to be affected by the common restriction and even misuse of the term. The tendency to confuse the issue of affairs with their origin is natural enough—and especially is this the case when the origin is complex and difficult to understand. Operations which are

the outcome of the Engineer's labour appeal to most persons because of their obvious utility, more forcibly than the conception, the initiation and the direction of the work. Thus it comes to pass that "Engineering" requires some assertion to prevent it from becoming entirely confused with mere manipulation. If the principles which the author now asks you to discuss seem of a recondite character, it will still be allowed that we may be properly employed in selecting from the stores of science the most suitable and appropriate methods in the exercise of the useful arts, even if their general application is not immediately obvious.

Can it be said that in the departments of applied science much progress has been made of late years in manipulative skill, or is the future likely to see much advance in this respect? Does it not rather appear that to the development of principles, to organisation, and to administration, we must look mainly for the advancement of engineering industry in every field?

It may well be asked how this applies to Engineering Survey Work. Slightly, perhaps, in respect of operations with chain and pole. The author does not invite the attention of the Society to the manipulation of surveying apparatus. No good purpose would be served by discussing that which in general can admit of little improvement on the part of competent and well trained operators. The point of view taken, in asking you to consider the processes that bring surveying within the province of the engineer, is the importance of understanding fully in what direction, and to what extent, scientific processes may be advantageously applied in our daily work.

To ascertain with precision the relative positions of points on the earth's surface, has been an object pursued by the highest intellects from the times of Hipparchus until the present day. The importance of such undertakings may be estimated from the active support they have received at all times from the most enlightened rulers and governments. We have become in this favoured country so used to the benefits derived from the foresight of our predecessors, that there can be but a faint conception of the real facilities we enjoy in a number of ways from the existence of the Ordnance Survey—a work that is without parallel in any country of the world. It is not too much to claim for it, that, imperfect as it may be in a minute detail where the features of a country change rapidly, its accuracy and comprehensiveness have helped in a large measure to the development of successful and useful Engineering enterprises, which would in its absence have been slowly discovered or would have languished from the time and

expense required to ascertain whether they were reasonably practicable. It is not, however, on this account that the work ranks as an engineering undertaking of the highest order, but because in design and in execution the great framework which supports the survey possesses unrivalled accuracy and adaption to its purpose.

Accuracy.—It is a matter of history how our Ordnance Survey developed from the measurements undertaken at the instance of the great astronomer Cassini to determine by direct measurement the relative situations of the Paris and Greenwich observatories. Facts alone need speak for the persistence of those who directed the survey, and for the precision of their work during a period of 60 years. When at the close of the main triangulation, the linear measurement of the base of verification on Salisbury Plain was compared with its computed length derived from the base on the shore of Lough Foyle, 350 miles distant, the difference amounted to 5 inches in a length of 7 miles—or about $\frac{1}{90000}$th part.

A still closer approximation is recorded in the determination of the Epping Base of the U.S. Coast Triangulation. The difference between the measured length of this base and its length derived from that of the Fire Island Base, 430 miles distant, was only $\frac{1}{200000}$th part—about one-third inch in 1 mile.*

The probable error in this system is stated as $\frac{1}{300000}$th part of any linear dimension. But, refined as that may appear, it is far surpassed by the recent determination of the longtitude of Madras. Here the probable error is but $\frac{1}{1000000}$th part, with which result, as the engineers justly say "no triangulation, however refined, will be able to compete at the end of 7000 miles until a knowledge has been gained of the shape and size of the earth more intimate than at present seems attainable." †

It is, of course, a debatable question in each individual case what degree of precision should be admitted in measurement. This applies in every department of engineering, and in none that the author knows of can a definite answer be returned. What constitutes precision of measurement? Supposing due care and attention to be given by the operator to his work, it seems obvious that the more refined the character of the apparatus employed, the more reliable the result. The general method of arriving at any dimension is to make several

* U.S. Coast Survey, 1865. Report of the Superintendent, page 192.

† Report on the recent determination of the longtitude of Madras, Calcutta, 1897, page 20.

determinations of it, and to take their arithmetical mean. We obtain three measurements, stated respectively, for ease in consideration, 75, 76, 80. Their arithmetical mean is 77. Does not the mind revolt from the conclusion that this figure is entitled to acceptance as specially near the truth? Does not the approximation of 75 and 76 appeal to one as, at all events, entitling the former to greater weight than the figure 80, which is relatively distant? even if we are not prepared to accept one of these actually measured quantities in preference to a derivative from them.

This is only an illustration, but the author ventures the opinion that far too much weight is attributed to "average" results in survey work. It seems to him that beyond securing some immunity from such definite errors as occur in the calibration of instruments, the repetition of measurements under similar conditions is of little value as a means to obtain an accurate result. The advantage of such repetition is confined to corroborating with more or less force the reliability of the several measurements considered individually.

It is, however, a different matter when the observation carried out is changed, so that the measurements are not of the same but of related quantities. Here the conditions are varied, and with changing conditions arises the question of probable accuracy in a manner which is quite comprehensible. The reduction of observations by the method of making the squares of the residual errors a minimum is familiar to engineering surveyors, and need not be discussed here.

Where the number of observed quantities is large, the computation of their most probable values entails labour that is only justified in operations of great importance and magnitude. The number of equations of condition in the Principal Triangulation of Great Britain and Ireland was 920; and even when taken in groups, the computations involved in one case the solution of equations with 77 unknown quantities. The author does not dwell upon this except to enforce the view that in the most refined measurements we are, after all, dealing only with probabilities—exactitude is an an abstract word. It may be said, how does this enter into ordinary engineering work? That is precisely the question the author wishes answered. Let it be thoroughly well understood what accuracy is attainable under any circumstances, and the engineer may be trusted to use his common sense to decide what he will treat as correct. But the principles of the subject are worth very careful consideration, if surveying is to be part of the engineer's art.

It is so often true that a matter is right because experience shows

it cannot be far wrong, that peculiar caution has to be observed in accepting fine measurements of any kind, unless they are the result of a habit of mind and practice in accord with scientific exactitude. Those who clearly understand what is attainable may well be relied on to judge fairly what is admissible. The author believes the geodetic work of many engineers is so well performed that they would not need to shirk marking a "probable error" on their plans. In some other departments of survey work, it is very doubtful whether such a course would meet with acceptance if proposed. The author submits that it is worth the while of engineers to improve further their methods and instruments for surveying purposes. It was in this effort for precision of measurement that the genius of Newton, of Watt, and of Whitworth, manifested itself most prominently, with what result is well known.

Now, granted that accuracy, and still higher accuracy, in surveying operations is desirable, in what direction is it to be sought?

Method.—It would appear that here, as in other branches of engineering, advance is likely to depend chiefly on improved methods and instruments. Personal skill in this, as in other departments of activity, soon attains its limit, *i.e.*, skill in the execution of merely mechanical and routine operations.

Surveying still implies very generally direct measurement of every distance by chain or tape, and some angular measures of which little advantage is taken, with such proof of the accuracy of the operations as may be inferred from the several lines measured, fitting decently into their places on a plan. This is serviceable enough for small and unimportant work; but the more that instrumental work and exact calculation can take the place of linear measurement, the more rapid and reliable will be the results. If the surface of the earth were like a billiard table, there would be more to be said in favour of linear measurement than there is under existing conditions, except when it is conducted with a refinement that is inadmissible on an extensive scale. The author is not, as indicated at the outset, speaking of the simple mapping of unimportant features in a plan, but of such a plan or such parts of it as may be relied upon absolutely in regard to the relative positions of the several features. Even where angular measurements are taken, the geometrical process of triangulation is still found to be largely persevered in, with an unnecessary number of measurements, and considerable uncertainty of result.

Triangulation is, and will be, always resorted to for fixing the positions of the main stations in any great survey. Not because a

triangle is a more reliable geometrical figure than any other, but because it is determined by the smallest number of observations. The pursuit of triangulation, however, on the grounds of its yielding, of its own nature, more accurate results than other methods is entirely fallacious, especially when applied to the complex features of a survey on a large scale.

A simple geometrical construction is well enough where angular measure is unknown or impracticable, but there is no need to resort to it in these days. Surveying by traverse was formerly regarded as a doubtful approximation, to be classed with the use of the plane-table and similar topographical expedients. The expense of good instruments may have partly accounted for this, and perhaps men's minds were more readily impressed by obvious geometrical notions than by the more subtle precision of trigonometrical tables and the facilities of logarithmic calculation.

In important survey work the traverse nowadays occupies a foremost place among skilled engineering surveyors.

There is, the author believes, still sold in opticians' shops an instrument called a "protractor." Some of his recollections are concerned with its use, and it has of course his full regard; but, notwithstanding that, he advocates the advisability of its abolition, and of letting a book of trigonometrical tables take its place. The bare notion of reading an angle to 30 seconds, and thereafter plotting the direction of the line with scrupulous care to an error of 30 minutes is illogical. Now the surveyor who still uses a protractor in laying down a plan, comes within sight of the truth when he plots a section. The fact is that since the days of Descartes human ingenuity has failed to discover a more accurate method of defining a point in a given plane than by its co-ordinate distances from two axes of reference. This principle is applied in all traverse work that need be considered nowadays, the axes being of course at right-angles. On this plan most, if not all, of the engineering survey work in our Colonies and abroad is carried out. As an instance at hand, the author may perhaps mention his survey of the Mersey Estuary of some 10 years back, which lies upon a meridian line through the centres of the towers of Hale and Weston Point Churches, extending from near Warrington to New Ferry. In such survey work every station on the traverse is fixed by its measurement along the axis from the origin and its rectangular distance from the axis. The plan is plotted as an ordinary section is plotted, without any of the uncertainty arising from intersections of groups of lines and with the security arising from

arithmetical proof of the value of every main point upon which a check line has been run before the plotting is begun.

The system of co-ordinate survey work alluded to partakes so much of the fundamental processes of geodetic surveying on the large scale, that it is remarkable how little it is used in many quarters. This is probably due largely to the remarkable completeness and accuracy of the Ordnance Survey in this country, which renders it in general unnecessary to construct independent surveys for any purpose. This is not so, however, elsewhere, and the surveyor who proposes to give any good account of himself in many of the fields of activity open in our Colonies and abroad, must be equipped with a knowledge of this work as well as with an intimate acquaintance with all the methods for establishing his position on the earth's surface. It seems to the author to be of the utmost importance that there should be a generally clearer understanding as to the use of precise methods in survey work of all classes, and the truth of the results attained as well as the desirability of connecting surveys definitely with the cadastral system of the country, if there is one, or otherwise, with the great reference points of the earth.

The co-ordinate system to which the author has alluded is the fundamental basis of all engineering survey work. To put it into execution, so far as the mechanical work of the survey is concerned, linear and angular measurements of the usual kind suffice; but to secure truth and coherence in the component parts of a survey of any extent it is in general required to determine meridians, latitude and longitude.

The meridian is, of course, easily found by observations of circumpolar stars at elongation. This was the method employed by the author in tracing a 40-mile line of aqueduct through unsurveyed country in Japan. Some engineers prefer to observe stars at equal altitudes, which is a good plan, but unless they are near elongation considerable practice in observing is required to get an accurate result, owing to the movement of the stars in azimuth.

These double observations are tedious and somewhat liable to failure through the sky becoming overcast in the intervals between them. A more rapid method, if the latitude is known, is the observation of the altitude of a star of known declination, when the azimuthal angle between the star and the pole is readily found and laid off by the instrument. It can be got also very closely by a single observation on the star ε *Ursæ Maj.* or when that star and *Polaris* are cut by a truly vertical circle.

Latitude is best determined by obtaining the zenith distances of

stars whose declinations are given in the Nautical Almanac. The declination of the observer's zenith being equal to the latitude of the place it is only necessary to observe the altitudes of selected stars crossing the meridian, which of course must have been previously fixed.

The altitudes of the stars are observed from an artificial horizon when ordinary surveying instruments are used, but if a properly mounted meridian circle is available the zenith distances may be measured directly as supplements of corresponding distances from the nadir to which the telescope can be easily sit.

It is worthy of notice how dependent are our measurements even of the most refined character upon some natural condition, the continuity of which is rather assumed than known. Here everything depends upon the surface of the mercury reflector assuming a position truly perpendicular to the earth's radius. But this implies a perfect direction of gravity towards the earth's centre that cannot be realised, when the many causes contributing to local attraction at any point are taken into consideration.

The establishment of longtitude, the third principal operation in important survey work of the class we are dealing with, is not quite so simple a proceeding as the two former. If we could procure an absolutely perfect chronometer that might be relied upon not to change its rate under the vicissitudes it must generally experience during the course of a survey, longtitudes would be simply read off that instrument by comparison with local time, wherever required.

Failing that, however, resort must be had to the motion of the moon, a timekeeper whose rate, ascertained through ages of observation, may be relied on absolutely by those who are obliged to read her position on the dial of the heavens.

The place of the moon among the stars, occupied instant by instant with unfaltering regularity, enables the surveyor to read off the Greenwich time wherever he may be, provided he carried with him a copy of the Nautical Almanac.

For purposes of navigation, the method of establishing longtitude by measuring lunar distances of stars given in the Ephemeris of the Nautical Almanac, is probably the best of those which are independent of the mechanism of chronometers. This involves a very accurate measurement with the sextant of the lunar distance and of the altitudes of the moon and of the other celestial body under observation, unless the latter are computed from the mean time of the place. The clearing of a lunar distance is no very difficult matter, although it involves some

arithmetic. The whole matter consists in calculating the angle between the apparent places of the bodies from their apparent altitudes and distance, and then computing their true distance from this angle and the co-altitudes corrected for refraction and parallax.

This method is, however, not to be compared for survey purposes with that employing moon-culminating stars. The difference in time between the transit of these stars and that of the moon across the meridian of the observer's place need only be accurately observed, and a reference to Greenwich time can be obtained from the tables in the Nautical Almanac, with very little calculation.

The advantages presented by this method in simplicity of observation with a theodolite and an ordinary watch, and the avoidance of instrumental errors and those arising from refraction, are obvious.

The author need hardly say that the most refined of all methods—that of comparing the local time of two places by means of electric signals between them—must be regarded as not within the reach of engineers in newly developed countries. As an engineering operation, however, demanding the exercise of the highest skill and care, it is unrivalled. It is the method lately used to show that the latitude of Madras has been for nearly a century officially recorded as 2 min. 27·54 sec. in error. This mistake, originating in the early local determinations made by means of eclipses of Jupiter's satellites, an astronomical method that need not be discussed here, was surmised 20 years ago. The proof now afforded by Lieut.-Col. Gore and Capt. Burrard, of the Royal Engineers, is one of the most interesting pieces of instrumental work that has been recorded of late years.

It may be suspected by persons whose experience is limited to our small island, that such operations as have been referred to are matters of hardly more than academical interest. But the author can appeal to you to concern yourselves with every subject that contributes to the activity and pre-eminence of our nation beyond the seas. And of all subjects, which is more vitally important to us than a true and accurate delineation of the features of the earth's surface? Notwithstanding the geodetic work performed by numerous explorers in the vast regions abroad which they have laid open to engineering enterprise, it must be admitted that with expanding civilisation more and more refined determination of the features and boundaries of those districts is essential. If our methods can be improved and abbreviated in this respect the time and trouble taken to consider them will not be thrown away. The author has already indicated the necessity that exists for those whose work may lie outside the bounds of our Ordnance Survey being

prepared to use engineering methods. As an illustration of what has to be done under such circumstances, he may refer to a piece of work carried out by Mr. J. C. Coode, M. Inst C.E., five or six years ago, in connection with a project for navigation works on the Desaguadero, in Bolivia. The length traversed was 240 miles, the route being sectioned as the traverse proceeded. Here were no Ordnance Survey points of reference. The only possibility of carrying out the work with any security, lay in frequent reference to the meridians, which from the direction of the survey were sensibly free from convergence, to terrestrial latitude and to longitude by the methods the author has referred to. The refinement attained in these observations was naturally inferior to that which would be sought with powerful and firmly mounted instruments in a sheltered observatory; but it need hardly be said that it was a work of great skill and endurance to observe moon-culminating stars at all with ordinary theodolites in open country, 13,000 feet above sea-level where the nocturnal temperature sank below zero Fahrenheit. A survey carried out on such lines, where every terminal point and station is definitely related to the axis and origin of the work, possesses a reliability and coherence that places it at once on the plane of mathematical accuracy, even though we concede that any individual element is at the best closely related to absolute truth.

The author will now touch briefly on the subject of levelling, about which indeed there is little to be said. It demands considerable operative skill and judgment, but nothing more. The spirit level is probably as good an instrument as will ever be devised for tracing a line of curvature around the earth. The word "levelling" is, of course, wholly erroneous as applied to its successive operations. The errors inseparable from the use of the spirit level are however well worth attention. First, there is the uncertain question of refraction, largely avoided by the plan of equalising each pair of sights, whenever it can be adopted. Next, error due to the effect of temperature on the frame of the instrument, uncertain in amount. Finally, the probability that the collimation is generally departing from the truth. Here the author's only item of information applies. One of the most valuable improvements introduced of late years into collimation apparatus is that due to our member, Mr. A. W. Brightmore, M.Inst. C.E., who, by simply applying a spring to one side of the diaphragm-frame working against a screw on the other side, is enabled to keep the instrument in perfect adjustment (whether level or theodolite) during periods that in former experience were never supposed attainable.

One thing about levelling operations is noteworthy. As usually performed by engineers, they are based on that system of reference to co-ordinate axes which the author has endeavoured to assert as the truly scientific basis of the location of points in the field no less than in the study. The author appeals to engineers whether there is not generally a feeling of greater security and satisfaction in relying upon the indications of a levelled section than upon those of a plan. A section possesses the great advantage that any point can be readily checked completely by re-measurement and re-plotting. In this respect the section possesses a definiteness and exactitude typical of the engineer's work in other departments. Can the same thing be said for many of our isolated plans in this country?

One of the most striking characteristics of the earth's surface in highly civilized places is its incessant change. When the author had last occasion to refer to the maps of Lancashire issued by the Ordnance Survey, they were nearly 50 years old, and in many places unrecognisable. It is doubtless a debatable matter as to how far it is reasonable and useful for a public department to survey and publish details of a surface which changes so rapidly. The author is aware that in Liverpool and in many other important places, a special staff is continually engaged in delineating the changes that are taking place. No doubt those surveys are linked into the general system of the country, in a manner which will at any time justify their incorporation with the National Survey. This, it appears to the author, is as it should be, not only for these special districts but for the entire Kingdom. Certain main fixed points having been once for all laid down, the author conceives the details of survey in any locality for any purpose may be advantageously and economically remitted to those whose particular interests are concerned with the matter.

For the labours of these persons to be generally useful, as well as of immediate service to their own objects, it is only necessary that uniformity of system should be observed. Let every station point be fixed by its co-ordinates, referred to axes defined as part of the conditions of the main survey of the country. Let this again be referred, as of course it always is, to the two great terrestrial properties—the direction of the earth's axis and the uniformity of its rotation; and the results will possess that coherence and be susceptible to that relation of one part to another that will entitle them to recognition as truly engineering work.

At this point the author finds himself, to borrow the words of a

great master of science on a similar occasion, at length on the threshold of his subject. It remains for you to decide whether it is one whose pursuit is worthy of attention. When the coherence and finish of our Ordnance Survey is considered, supported as it were upon the fundamental frame of space and time, the 1-inch plan upon the Delamere meridian, the 6-inch plans upon their respective county meridians, the author cannot help thinking that it would be advantageous, even in Great Britain, to harmonise practise in our numerous isolated surveys. If, in place of the North Point which enriches the appearance of so many plans, the local meridian was stated, and if for any reason, not a true geodetic meridian, fixed by the latitude and longitude of points in the National Survey, coherence would be secured.

If, further, the lines of local surveys were treated traversewise, and their stations were co-ordinated with the local meridian or axis, there would, the author feels convinced, result a degree of certainty and simplicity in both surveying and plotting which would possess more than merely local value.

The point in which traversing is weak is the use of linear measurement. This earth's surface is so ill adapted for such measurement that after the apparent length of a base line has been measured in the most eligible situation, with all the apparatus scientific refinement can suggest, the observed length before an engineer can use it must even then be corrected for inclination and for elevation above the mean surface. Independent traverse work must be checked by and related to astronomical data; but where many points of reference are already fixed no such trouble is involved, the computed position of every main station indicating the admissibility of the lines that connect with it.

A statement has been lately published to the effect that the Yukon district is to be mapped out in rectangular plots bounded by north and south, east and west lines. It is not to be doubted that there is some compositor's error here. Either the plots will not be rectangular, or they will not have those boundaries. In latitude sixty-five a plot running north and south through a single degree will measure about 190 feet different in every mile of its parallel extremities.

With this simple illustration of the need there is to know and to consider the facts disclosed by scientific enquiry in undertaking the delineation of the earth's surface, the author leaves the subject to your consideration.

DISCUSSION.

Mr. Robert E. Johnston said—I have had little or nothing to do with surveying, but I do not quite follow the question of averages, because I take it that in nearly every human work averages must be introduced. In taking the longitude an astronomer has to have a series of lines across the telescope recording the passages from one line to another on his telescope, and thus strikes an average of the time of the passage.

With regard to ordinary engineering levelling, I think it is very much worse than it used to be. In the old canal days an engineer was bound to be accurate or water led him into trouble.

Mr. Henry H. West said—Supposing we had to take the average of a series of figures the majority of which lay very close together, as in the illustration given by the author, and there were two extremes which were a long way wide of all the other observations (especially if the observations that were close had been arrived at by independent methods), we should very properly discard the two extremes, and take our average from the others, coupling them in pairs and taking the arithmetical mean of the pairs. The mean in this particular illustration would have been 66·7, which would have been fractionally wrong, but still near to the truth. I think no one who has read the history of the Ordnance Survey, can have helped being struck with the marvellous accuracy of the results. That a line of 7 miles in length, measured by the most careful and accurate linear measurement, should only vary from the calculated length by 5 inches is very wonderful.

Mr. W. E. Mills said—As one of those who have, perhaps, had some little experience in the artizan's department of surveying, there are one or two points that I should like to remark upon. We must all admit what I may call the keynote of the paper, and that is, that surveying as at present practised is capable of greater accuracy, but we have to consider in all matters relating to civilisation that if you arrive at a result which fairly gives you what you require you have obtained what will satisfy you, except in so far as the theoretical point of view is concerned.

For example, the ordinary use of land surveying is to ascertain the area of a given piece of ground. You proceed to survey that ground with the best means at your disposal, and you arrive at the result. A second surveyor arrives at another result, and a third at another. These results may be tolerably near one another or very

wide apart. Assuming that they are tolerably near, the method of taking the mean—although the author describes that as being a very unscientific way of arriving at the truth—is generally accepted as being fairly the right thing. I was rather surprised to hear that our Ordnance Survey is a work without parallel in any country of the world. I was under the impression that European countries had devoted a considerable time and expense to surveys of a similar nature conducted by a Government department. I have certainly seen some very admirable maps published in Vienna by the Austrian Government, and I should like to know whether the author's words simply mean that the surveys of other countries are not of the same extent as ours, or whether it means that other countries have not undertaken an Ordnance Survey. The difficulty with any survey of a country is that it must daily become more or less obsolete, and I do not know how you can obviate that difficulty, unless, as in one part of the paper the author rather foreshadows, there should be—as it were—a local office established in large towns, or where the survey is likely to change rapidly, which should, from time to time, revise and correct the plans as published.

I am afraid the British taxpayer, burdened as he is in many ways, would resent a very large increase in the vote for the Ordnance Survey, which such a plan as that would mean.

The author speaks of the general way in which surveying is done, but I do not know that I should not question his statement with regard to very little advantage being taken of angular measures. So far as my experience goes, a great deal of importance is attached to these angular measures, for checking, at any rate, and some of the means which he has described are used for doing it. We must, of course, always remember that the surface of the earth is not like a ball; I believe we have always a curvature, and therefore assuming that we could by means of the instruments at our disposal obtain a perfectly accurate length of line, that line would not be in a plane, but in a curve, and would require correction for that alone. After that his plea for greater accuracy is of academical advantage rather than practical.

The author also states that triangulation is entirely fallacious. I would like to ask him what process he would consider, assuming a large survey to be the subject, superior to that of triangulation.

The "protractor" I think is doomed, although perhaps for small work it may still be of use, but unquestionably it is only a means to an end.

There is no doubt that some means of ascertaining the position is absolutely necessary for those who have to go abroad in unsurveyed countries where there is nothing to guide the surveyor.

Dr. J. H. T. Tudsbery, in reply, said—It is 10 years since I read a paper before this Society, and I am sure that with such encouragement as I have received from you to-night, it shall not be 10 years before I read another if you will have one.

One reason I had for choosing this subject was that I did not think the Proceedings of the Society contained any account of the simple astronomical methods that can only be found out by burrowing into works treating of such methods.

Your chairman is well acquainted with the works of astronomy that deal with these subjects, and I think he will bear me out in saying that there are not very many books in which engineers can find even roughly an outline of how to establish their position on the earth's surface.

I quite admit the force of Mr. West's observations about averages. I was only led to refer to the matter of averages because it appeals to me as a very inscrutable thing that we should take a certain measurement three or four times over, repeat it every time with scrupulous care, and then ignore every one of these measurements and adopt a different.

In regard to surveys of other countries, there are on the continent of Europe some excellent surveys, but I have the highest authority in support of the statement in my paper that in completeness, accuracy and finish, the British Ordnance Survey is absolutely unrivalled in the world. The origin of the survey was to establish the latitude of Greenwich in relation to that of Paris, and then it occurred to some enlightened minds that it would be desirable to cover the whole of the Kingdom with a network of triangles. The result has been a very complete survey of great use. One point that I think has escaped observation and to which I would like to refer, is that it seems hard that people should be taxed in order that elaborate plans may be made of places that nobody wants to use, and that will change their features before the plan is made use of. What I would suggest is, that after fixing main points and features such as churches, roads, &c., it should be left to those who want a plan to make their plan when they want it, and not to make at the public expense these elaborate plans of details, which are absolutely useless after a few years.

As regards local surveys, I do not mean my words to imply that there should be any more officials, but I would suggest them where

there are necessarily already working groups of surveyors. In such towns as Liverpool, for instance, where there is always a strong force of surveyors actually re-surveying the town, it would be a good thing that such surveys should not be purely local, but that they should be related to the national cadastral survey so as to secure a coherence in the work of the whole country at the least possible expenditure.

In regard to triangulation, we fix our positions by linear and angular measurements, but so you do if you use any other geometrical process. The disadvantage of triangulation is that for the purpose that you usually want to employ a survey in engineering you have to measure more lines than you have absolute need of. In working by traverse you generally measure the line you wish to use.

If the co-ordinate system is adopted so that you do not depend upon plotting for the accuracy of the work you find your position arithmetically. A book of mathematical tables is less likely to lead to error than a measurement on the grounds; therefore if you use trigonometrical tables and reduce all your lines by sines and co-sines to co-ordinate dimensions, and plot the whole thing by co-ordinates, you have not only the ease of plotting, but you have before you in your book the absolute position in space of every point that you are dealing with.

One more observation only, and that is generally as to refinement. Those who have spoken have entirely apprehended me in saying that the keynote of the paper is that we should endeavour to work to as fine a degree of accuracy as possible. I do not object to saying that experience tells you when you have the refinements necessary for practical purposes. None the less I do say that we should not, when there is no greater trouble or expense concerned, refrain from adopting a method merely because we are unused to it, if it will assist us to obtain higher refinement in our work.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

TENTH MEETING—16TH MARCH, 1898.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,

PRESIDENT, IN THE CHAIR.

TELEGRAPHY BY ELECTRIC WAVES ACROSS SPACE.

By OLIVER J. LODGE, D. Sc., F.R.S.

THE system of telegraphy which has excited so much interest lately is, as you know, performed by the emission of electric waves set up by electric oscillations. These electric oscillations have been known to science ever since 1853. They were surmised by Joseph Henry Washington in 1840, and by Helmholtz in 1847, but in 1853 Lord Kelvin gave their complete theory; which was based on the fact, at that time perfectly unknown to most electricians, that electricity behaved like matter in that it possessed inertia, or rather that it behaved as if it possessed inertia. I will not say it does possess inertia, because I imagine that would be the same thing as saying it is a form of matter. I do not know that it is not, but you see it stated sometimes that it is a form of energy. It can possess energy, but it need not be energy on that account; for instance, there is hydraulic energy, and yet water is not a form of energy. From a great height, or under pressure, it possesses energy, and a stream possesses energy, and so it is with electricity. Electrostatics deals

with electricity at high pressure, and you may have electricity in motion in the electric current. It very much resembles a form of matter; its kinetic energy depends upon a sort of inertia, and it displays this inertia only whenever it develops the phenomenon called magnetism. You have necessarily magnetism wherever you have an electric current.

Now in order to produce mechanical oscillation, for instance for a sound vibration, two things are necessary, elasticity or something to initiate the oscillation, and some kind of inertia to prolong it. Why does the oscillation die out? For two reasons, and sometimes for three. Partly through ærial friction, if it does not take place in a vacuum; partly by reason of internal friction; and third, and most important, by reason of radiation if the vibration takes place in a medium competent to transmit waves. The energy of vibration is consumed partially in the production of such waves. The energy of a ship is mostly consumed in producing certain well known waves, and these remain as the equivalent of the enormous horse power employed in an Atlantic liner. If you have a body vibrating in the air, waves are set up as in water, but not only on the surface. So it is also in the ether. Electric vibrations occur, that is the first step, and they behave like sound vibrations in transmitting waves, which is the second step. Lord Kelvin showed that electricity possesses two properties, those of vibration, or elasticity, and of inertia. It surges backwards and forwards like water in a bath, and it will surge in this way half-a-dozen or a dozen times, the oscillations being exceedingly rapid, for they go with the velocity of light. The vibrations per second will be something like 50 or 100 millions—it depends on the size of the apparatus. In 1853 Lord Kelvin showed how you can calculate this rate of vibration. The fact that light waves set up by oscillations can be conveyed by the ether was, of course, a matter of ancient knowledge, being, in fact, ordinary light; but the fact that these light waves are electric waves was discovered by Clerk Maxwell in 1865, but he did not know how to produce them. The suggestion how to produce them was made by Fitzgerald, of Dublin, in 1880, by the opening out of a Leyden jar, and letting the electric and magnetic disturbances overlap and conjointly affect the same region of space. One end was positive, the other negative, and the electric lines of force filled the region between as an electrified field to a great extent and a great distance. Up to this time detectors had not been invented, consequently we could not show that the waves were there; but this great discovery was made in 1888 by Hertz. He

found that the waves impinging upon a conductor disturbed it sufficiently to make it give off sparks. The waves radiating from a discharging conductor fell upon a wire or upon a similar conductor and set up sympathetic oscillations. Some of this splashing and sparking had been casually observed before, but had not been understood.

ILLUSTRATIONS BY EXPERIMENTS.

The "coherer" is another and far more sensitive mode of detecting waves. It was observed by the lecturer in 1888, and in 1891 was applied by Branly to the detection of waves. With this arrangement waves can be detected several miles off, and can be made to work any telegraphic receiver. The principle was shown in Liverpool, London and Oxford in 1894. But the public has only realised it quite lately —through the energy of Mr. Marconi in bringing known facts home to newspaper reporters and magazine article writers; scientific papers being useless for exciting public interest. I do not know if this wireless telegraphy will be of much use as yet; I suppose it will be of use some time. Everyone can hear any message sent unless it is sent in a particular note, which can only be received by a corresponding receiver. I here show actual large-scale apparatus, constructed by my partner, Dr. Muirhead, for this very purpose of discriminative communication by means of Hertz waves; but, besides this plan, I have an entirely new method which I have hopes of, and which will send messages big distances. It does not depend upon waves at all, but upon magnetism, which is independent of obstacles, and that is a great advantage. I think it may be used over great distances, even for signalling ships while still at sea. But it will take another paper to explain this.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

ELEVENTH MEETING—30TH MARCH, 1898.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,
PRESIDENT, IN THE CHAIR.

Mr. D. GABRIELSON was duly elected an *Associate* of the Society.

The President announced that the Trustees of the "West Premium," on the recommendation of the Committee appointed by the Council, had awarded the Premium for the past Session to Mr. WILLIAM BRODIE, *Member*, for his paper read on the 3rd March, 1897, entitled "Dock Gates."

THE MASONRY DAM PROBLEM.

By A. W. BRIGHTMORE, D. Sc., M. Inst. C.E.

THE author's reason for selecting this subject for discussion to-night was not so much on account of its intrinsic interest, which is, however, considerable; nor yet for its novelty, for the Society was favoured some years ago with a very exhaustive and interesting paper by the worthy President, which the author will make no attempt to emulate; but in choosing this subject he was guided by a consideration of the advantages it gives, incidentally, for alluding to the relation of scientific knowledge and practical experience in designing such works. He uses the word "scientific" knowledge in preference to "theoretical," not because it describes his meaning any more clearly,

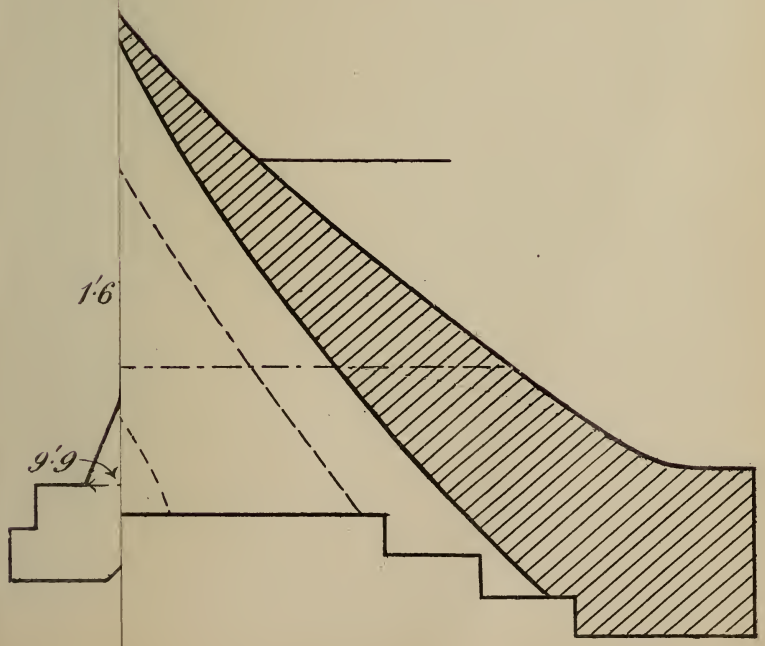
RY DA

PLATE VIII.

OUZEY DAM.

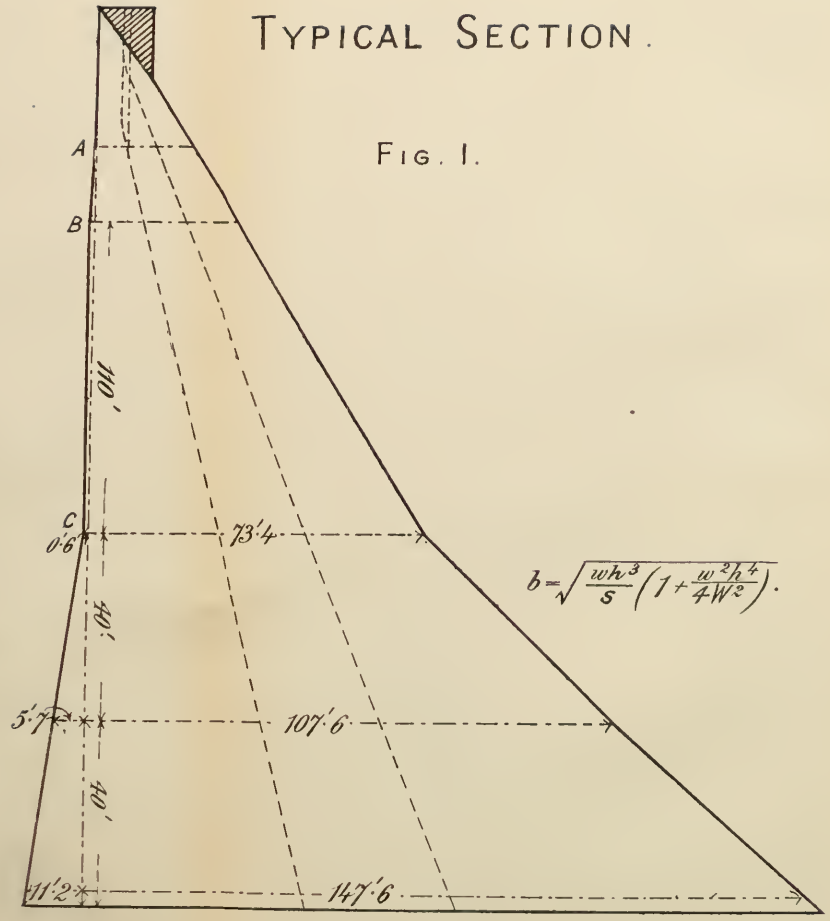
T.W

FIG. 3.



TYPICAL SECTION.

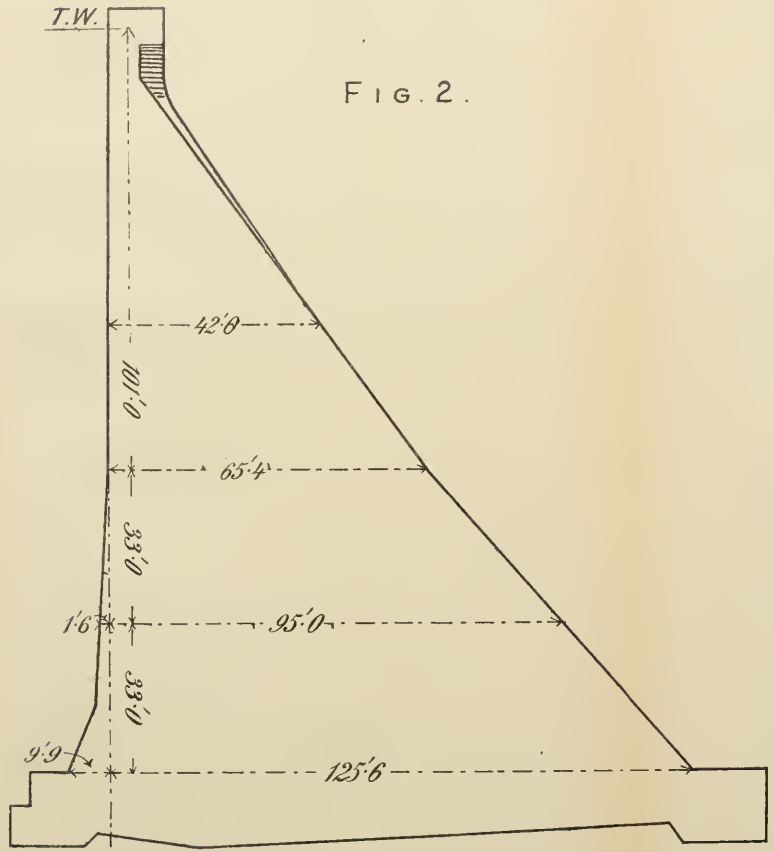
FIG. 1.



$$b=\sqrt{\frac{wh^3}{s}\left(1+\frac{w^2h^4}{4W^2}\right)}.$$

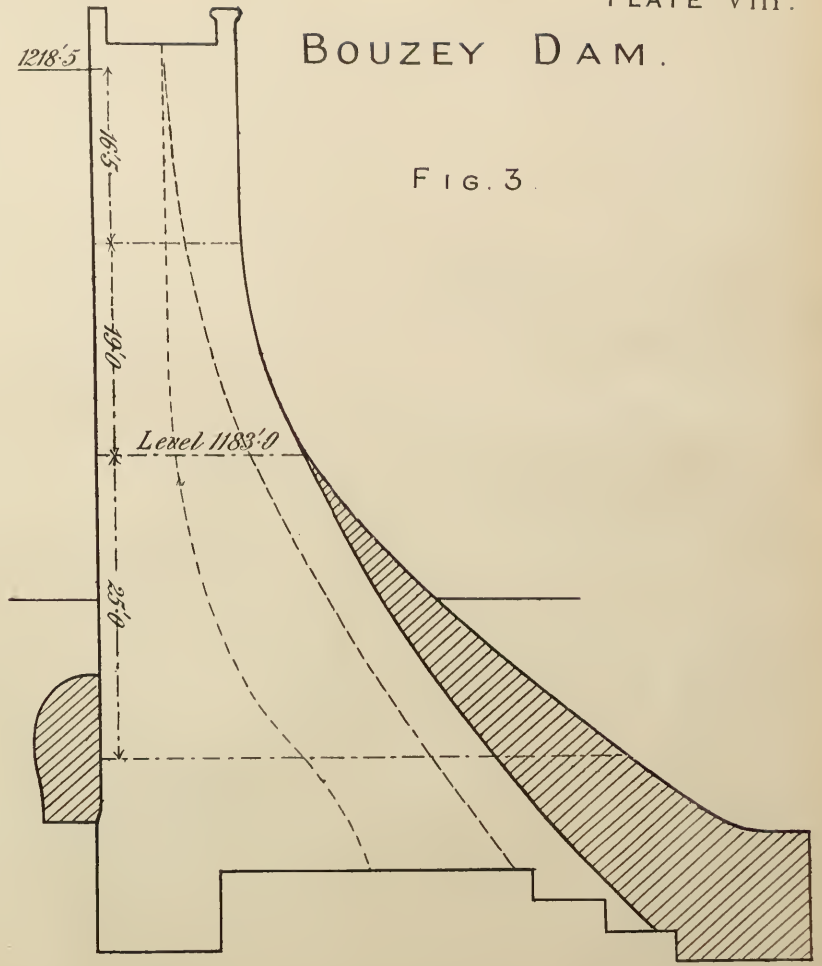
CHARTRAIN DAM.

FIG. 2.



BOUZEY DAM.

FIG. 3.



George Reed & Co. Lithographers, 64, Stanley Street, Liverpool.

but because the meaning of the latter word has often been perverted and might lead to misunderstanding. The word "theoretical" has often been improperly applied to the result of a calculation, without regard to the consideration of whether the premises, on which the calculation was based, include all the fundamental conditions of the problem to be solved; whereas no result can properly be styled "theoretical," unless the proposition is one which admits of all its elements being defined in such a manner that they enter into its solution. A word seems to be wanted to represent a result which is based on only an incomplete incorporation of the factors of a problem. However, the author will not attempt to invent one, but contents himself with pointing out a want, and the sense in which he utilizes the expression.

There are two ways in which a problem of this kind may be approached :—

(1) An attempt may be made to calculate the theoretical figure on certain stipulated assumptions.

(2) It may be argued that it is quite impossible to calculate the stresses at every point in such a structure with any approach to certainty, because no assumptions that can be made would adequately fit the actual conditions of stress in it; from which it is concluded that the design can only be evolved in the brain of those who have had considerable practical experience in building similar structures.

The author proposes to attempt to show that both these contentions are correct as far as they go, but require to be taken together to arrive at a satisfactory result, and he will try to assign to each its proper function and limits.

It may be admitted at once that it is impossible, by any mathematical expression, to specify the conditions of stress at every point in a masonry dam or similar structure; but, on the other hand, it is possible to make certain assumptions which will fit the average conditions under which such structures exist. Many cases at once present themselves to the mind in which an excessive stress at one point very soon distributes itself, so that an average condition is restored. It is only necessary to instance the case of a riveted joint, where the stresses in the plates are more or less concentrated between the rivets, but a short distance off the stress becomes uniformly distributed. Also, it is easy to find a law that will apply between certain limits, when the range between such limits is small, as in the present case. Difficulties arise when it is attempted to find a law that applies between very wide limits, as conditions, which may be unimportant at one stage, come into prominence at another.

Very few physical laws, when pushed to extremes, continue to express correctly the facts of the case; even that faithful servant "Ohm's Law" is suspected of having exceptions under certain extreme conditions. But when, as in the present instance, the range is small, such difficulties do not obtrude themselves.

Before practical experience can be applied, it is necessary to have some framework to go upon; the solution of the problem must be known under certain conditions, which would fit the case under favourable circumstances; then the work of practical experience comes in to introduce such alterations as previous experience of the departure of the actual conditions from the primary assumptions, and the circumstances of each particular case may suggest.

The author will illustrate his meaning by using, as a simile, the problem a tailor has to solve in fitting his customers with clothes. By measuring numerous individuals he instinctively finds that the various measurements fluctuate about certain averages; so that the problem he has to solve is to accommodate his clothes to any given set of variations from the average dimensions.

The problem to be solved by the engineer, in designing such a structure as a masonry dam, differs from the above in this respect;—and here comes in a notable superiority of the engineer over the tailor—that he has first of all to design, by calculation, a structure to fit the average conditions, which is ready to hand in the former case by simple measurements.

Thus the engineer's scientific knowledge enables him to evolve a typical design, which his practical experience accommodates to any given set of variations from the premises in the typical case.

It is sometimes said that, as the typical design cannot be applicable without allowances to cases in practice, it is unnecessary to go very carefully into its solution. The author thinks it is hardly necessary for him to insist on the fallacy of such an argument, for it is evident that, unless the typical case is solved within the limits of accuracy to which the final design is required, it is practically useless as a basis to start from in evolving the necessary design for any particular case; for under such circumstances any alteration to suit an actual case would make the resulting design equally wrong.

Furthermore, in evolving the typical design it is very necessary that the premises should include all the fundamental conditions.

The pioneers in the exact method of designing such a typical dam were the French engineers, Sazilly, Graëff, and Delocre. In their premises, however, they omitted one condition that is now

considered essential, which is, that there should be no tension in a masonry dam; also they dealt with the pressures on the horizontal planes, instead of the actual maximum pressures; however, with these exceptions, they solved the problem in an exact manner with much ingenuity, but the method is cumbersome. When it is remembered that it involves incidentally such exercises as the solution of equations of the sixth degree, it is not to be wondered at that the method of solution has not commended itself generally to engineers. But the results of the method have been made available by Rankine, Bouvier, Molesworth, and others, who have proposed empirical formulæ which cover the results of the above calculations. Considerable judgment must, however, always be exercised in the use of empirical formulæ, which hardly ever include all the varying conditions, such as, in this case, varying height, specific gravity of the building materials, and limiting intensity of pressure allowable.

It is interesting to mention that Rankine's investigation for the Tansa dam, when originally proposed, was the first time that the condition—that there should be no tension in the masonry of a dam—was insisted upon, it has now been adopted by the French engineers.

Mr. Bouvier has shown that the maximum stress in a dam is not on the horizontal plane, but on a plane perpendicular to the direction of the resultant pressure.

A simple direct solution of the problem, in a manner that readily appeals to engineers, without introducing tentative graphic methods, appears to be a matter of importance. The premises, on which the following solution is based, are as follows:—

(1) The maximum compressive stress on any plane, at either the inner or outer face of the structure, shall not exceed in intensity a safe limit—found in existing works to be between 6 and 12 tons per square foot.

(2) There shall be no tensile stress at any point of the dam. This involves that, under all conditions of loading, the resultant stress shall not, in any vertical plane, fall without the middle third of the dam.

(3) The resistance to shear in any horizontal plane shall be greater than the total horizontal thrust of the water above the level of that plane.

The observance of the first two conditions generally involves the fulfilment of the third.

Condition (2) assumes that the dam is rigid, so that the stress varies uniformly in any plane. This assumption has given rise to a good deal of contention at different times; but it would appear that the

chief objections to it are based on attempts to apply the principle to extreme cases, which do not occur in the solution of the problem under consideration. It will be observed, in support of this assumption, that the resulting form for a masonry dam is one which appeals to the senses as a very rigid shape; also, it must be remembered how small is the range of stress to which the masonry of the dam is subjected, 10 tons per square foot being generally the maximum permitted, and it it often considerably less; whereas, the crushing stress of Portland cement mortar is often 200 tons per square foot, and that of the stone generally much higher.

With respect to the condition requiring that there shall be no tension in the dam, it has been stated that although it is obviously desirable that there should be no tension at the water face when the reservoir is full, where any crack would be liable to be filled with water under pressure, which would cause an uplift; yet tension when the reservoir is empty, at the downstream face, is a matter of no consequence. This is a contention from which the author dissents, because even in a structure in which the materials have considerable tensile strength, the elastic limit, below which the working stress must be kept, is lower when the stresses to which they are subjected vary in sign, than when the stresses are always of the same sign; consequently in a dam built of masonry whose tensile strength is so unreliable, it is obviously better that there should be no reversal of stress under different conditions of loading. To ensure this, in a dam, in which the intensity of stress at every point varies with the fluctuating height of water in the reservoir, it is necessary to arrange to have a slight compressive stress at the outer toe when the reservoir is empty, and at the inner toe when the reservoir is full.

The reason why the investigation of this typical design has not been considered indispensable is that the problem admits of numerous solutions that satisfy all the above conditions; but there is one solution which gives a section of minimum area, *i.e.*, one that involves the use of the minimum amount of material in building the dam. It is obviously desirable to approximate as near as possible to this minimum section, which is equally as strong as other properly designed sections requiring reduntant material, and stronger than improperly designed sections with an excess of material, which is a positive harm.

By graphical methods designs may be elaborated to fulfil the above conditions, but to obtain the minimum section in such a manner involves considerable labour by reason of its tentative nature; and

moreover, graphical methods, although useful to illustrate mathematical processes or for checking calculations, should not be regarded as a substitute for exact methods of calculation, when the problem admits of such.

When a problem is incapable of exact deductive solution, the next best method is to reduce the tentative part of the solution into a factor, which is of minor importance, whose effect on the result is trivial. This is done in the following method, the tentative part of the solution only entering in a very subservient manner.

A high masonry dam may be divided into three parts; the first, that in which the maximum allowable intensity of pressure is not attained at either the inner or outer faces; the second, that in which the maximum intensity of pressure is attained at the outer but not at the inner face; the third, that in which the maximum intensity of pressure is attained at both the inner and outer faces.

In Part I. the resultant pressures, reservoir full and empty, fall at the outer and inner thirds of the breadths respectively; and, as Rankine has shown, the section requires to be a triangle whose inner face is vertical, and of which the cotangent of the vertical angle equals the square root of the specific gravity of the masonry. Fig. 1, Plate VIII., shows the section calculated—assuming the specific gravity of the masonry equal to 2·25, and the limiting intensity of stress equal to 10 tons per square foot. The triangular hatched portion at the top has to be added to resist wave action, and sometimes to carry a roadway. That does not affect the conditions of the problem down to the point A, at which the vertical through the centre of gravity of the triangular piece cuts the inner one-third of the breadth; below that point, the resultant weight of the dam, including the triangular lump, falls in the inside third, and continues to approach the inner face down to the point B, where the weight of the triangular piece becoming insignificant compared with that of the dam, it recedes from the face. A batter must therefore be given to the inner face between A and B. Below B to the base of Part I. at C, the inner face may be vertical. The effect of the batter is to bring the resultant, when the reservoir is full well within the middle third.

In Part II., the introduction of the condition that the pressure is the maximum at the outer toe, necessitates the resultant, reservoir full, being inside the middle third. The proportions of Part II. of the dam can be easily calculated * by causing the resultant of the weight

* "The Principles of Waterworks Engineering," 2nd Edition, by J. H. T. Tudsbery and A. W. Brightmore, page 220.

of the dam above any level, and of the water over its inner face, to fall at the inner one-third of the breadth at that level. This condition has the effect of always ensuring a slight compressive stress at the outer toe when the reservoir is empty, and with its help the following formula is easily rigorously deduced :—

$$b = \sqrt{\frac{w\ h^3}{s}\left(1 + \frac{w^2\ h^4}{4\ W^2}\right)}$$

where b is the breadth at a depth h below the crest;

W is the weight of the masonry above b, and of the water over the inner face;

w is the weight of unit volume of water;

and s is the maximum stress allowable in the dam.

This formula gives the breadth at any depth in terms of that depth and of W. At first sight it would appear that the presence of the latter factor would render the formula useless; but examination shows that the term containing W is small compared with the first term in the formula; in fact, it ranges from $\frac{1}{6}$ to $\frac{1}{8}$ of the whole expression between the depths of 110 and 190 feet; so that if W is known, even approximately, the breadth can be readily and accurately found. Thus the tentative part is thrown into a factor of minor effect; by considering successive laminæ, the breadths are simply calculated; and by taking moments about the inner one-third of the breadth, the projection at the inner face is deduced without either finding the centre of gravity of the dam or of the water over its inner face. This method of calculation, it will be seen from the diagram, applies, with the data taken, to a dam up to 190 feet high.

It will be noticed that the only redundancy caused by making the resultant of the weight of the dam, and of the water over the inner face fall at one-third the breadth from the inner face, is the making of the batter on the inner toe straight instead of slightly hollowed. Thus such excesses as exist are advantageously placed.

The same method of calculation can be extended to Part III., where the limiting stress is attained at both faces, but as there appears to be no likelihood of a dam of such a height being built in the near future, the author will not consider it now; for even in America, that land of enterprising engineering, the projected Quaker Bridge dam in connection with the water supply of New York has been abandoned and superseded by a less impressive structure.

In support of this method of design the author has shown in Fig. 2,

Plate VIII., one of the latest French dams, *i.e.*, the Chartrain dam, of which Mr. H. Marius Bouvier says: * "It may be considered as actually "representing the final word, with regard to the researches made "in France, on the subject of the construction of works of this "kind."

It will be noticed that there is a remarkable similarity in the results of the two methods of investigation. The maximum pressure in the Chartrain dam is 9·1 tons per square foot, as compared with 10 tons in the dam shown in Fig. 1, which accounts for the slightly reduced width in the latter case. The Chartrain dam is situated on the River Tâche, an effluent of the River Renaison, which flows into the River Loire at Roanne, and the reservoir formed by it, contains when full 880 million gallons, and supplies the town of Roanne with water.

The dam was commenced in 1888, and finished in 1892. It is built to a radius of 1300 feet, and is 720 feet long at the top. The foundation is on granite, and the dam is built of the same material, undressed, and with mortar made with Ardèche lime.

Attempts have been made to calculate the assistance a dam receives from the support at the ends where it is tied into the ground, but such calculations are rendered superfluous by the fact that it is no uncommon occurrence for a dam to crack across in a vertical plane more or less perpendicular to its length, owing to changes of temperature, which in a properly designed dam has no prejudicial effect on its strength.

The adoption in a masonry dam of a certain amount of curvature helps it to take up, with less chance of cracking, the variation due to temperature, but such curvature, unless it is to a comparatively quick radius, has no effect in increasing the strength of the dam, and consequently does not permit of the section being reduced.

After instancing a dam built in accordance with scientific design, the author cannot do better than refer to the effect of disregard to the dictates of science in the now well known case of the Bouzey dam, which is, however, extremely instructive. †

Fig. 3, Plate VIII., shows the section adopted for this dam. It was approved of by the Council of the Ponts et Chaussées on the understanding that the dam should not be raised at once to its full height, but that the water should be kept provisionally at a level of

* Fifth International Congress on Inland Navigation. Report on "Reservoirs in the South of France," by H. Marius Bouvier, page 19.

† Report of a Special Commission of the Ponts et Chaussées.

1212·0 feet above datum, and not be raised to its ultimate level, 1218·5 feet, until the dam had thoroughly consolidated. The dam was straight, and its length was 1700 feet, the contents of the reservoir at the provisional level being 1034 million gallons, and at the final level 1540 million gallons. The dam was built on the new red sandstone, which was fissured and permeable, and to prevent the water getting underneath the dam a guard wall was carried down beneath the water-face into the solid rock. The guard wall was built in 1878 and 1879, and in its construction springs were met with that were with difficulty sealed. The dam itself was built up to the level of 1187 feet for a length of 820 feet in 1879, and completed in 1880. During its construction the engineers, on representing to the Minister of Public Works the greatly increased storage that would be obtained at a small additional cost by at once raising its height to the ultimate level, obtained permission to do so.

The filling of the reservoir was started in November, 1881, about a year after the completion of the masonry. When the water in the reservoir attained the level of 1187 feet, springs appeared on the lower side of the dam, having a flow of about 2 cubic feet per second. In December, 1882, two fissures, distant 243 yards and 332 yards respectively from the overflow, were noticed in the dam, and supposed to be due to changes in temperature. These caused the discharge of the springs to increase to 2·6 cubic feet per second. On the 14th March, 1884, when the level of the water in the reservoir was 1210·0 feet, a length of 444 feet of the dam suddenly assumed a bent form between the points 119 yards and 267 yards, and the flow of the springs increased to 8·1 cubic feet per second. The height of the water in the reservoir was kept constant for a year after this. No further movement took place, and the flow of the springs remained nearly constant.

In 1885 the reservoir was emptied to see what had happened. It was found that the dam had separated from the masonry wall beneath it, between the points 148 yards and 247 yards, still keeping vertical, the greatest deviation from the straight being 1·1 foot at the centre of deflection; and on the inner face, at each end of the displaced length, was a group of fissures. The cracks at the centre of the deflection were visible only on the outer face. Fissured and permeable beds were found, which passed beneath the foundations of the guard wall.

Following the recommendations of a special commission of the Ponts et Chaussées, it was resolved to form an abutment of masonry,

shown hatched in the diagram, on the solid rock at the outer toe of the dam, starting at the level, 1182·4 feet, drains being laid through the masonry to lead away any water percolating underneath the dam. A wall of masonry was also to be built on the water side at the junction of the guard wall and the masonry of the dam proper, and covered with puddled clay. The fissures were to be filled with cement grout.

These works were finished in 1889, and the refilling with water commenced in November of that year. The flow of the springs increased from 0·5 cubic foot per second, to start with, to 2·8 cubic feet per second on the 15th May, 1890, when the level of the water in the reservoir was 1218·5 feet above datum. The level of the water was raised each year to 1215·5, and was never lower than 1201·6 feet. On the 27th April, 1895, when the level of the water in the reservoir was 1218·2 feet, a length of 594 feet of the central part of the dam was suddenly overturned at the level 1186 feet, between the points at the distances 149 yards and 347 yards respectively. This length includes all but 90 feet of the part displaced in 1884. The fracture was nearly level longitudinally, and transversely it was level for 12 feet, and then dipped towards the outside.

Calculating the stresses at the level 1182·4 and above it appears there was a maximum tension of 1·3 tons per square foot at the inner face. The fissures had not been properly filled with cement grout, but had been closed on the face by means of tarred yarn fixed with wooden wedges, but were left open in the interior. One fissure communicated with an oblique crack, and a dangerous uplift was caused at that point.

In the first season's building the dam was built up to a level of 1187·0 feet, and about 18 inches was taken down on restarting work next season, consequently a weak place at the junction of the two seasons' work occurred at the same section in which tension existed.

Owing to the tension, the oblique crack tended to extend until the structure was destroyed.

From the two failures of this dam are exemplified the following points:—

(1) The necessity of a satisfactory foundation, and of provision for leading off by drains all springs.

(2) The advisability of having no tension in the structure, because any horizontal crack that may form tends to extend thereby until the structure is endangered.

DISCUSSION.

The President, Mr. George Farren, said—There are only one or two points to which I should like to allude. In the middle portion of the paper the author says that Rankine has shown that it simply requires to be "a triangle whose inner face is vertical, and of which the "cotangent of the vertical angle equals the square root of the specific "gravity of the masonry."

At first sight that seems to be a pretty large order, and it wants some amount of thought. I have no doubt that everybody in the room understands the problem, but even for those who do understand it I would recommend them again to read Rankine's description of that triangle, and also especially to read the work of which the author of the paper is one of the joint authors. I have myself been all through the mill, and I strongly recommend everybody to get up these facts, because the notion that the square root of the specific gravity of any particular material shall determine the height and thickness of a dam does seem at first sight a rather startling thing.

Talking about the Chartrain dam, which I have seen, I would ask you to compare it with the Bouzey dam.

It was a very good thing indeed when Rankine pointed out that question of the middle third on which the whole question depends.

That Chartrain dam is one of the finest ever built, although there is a larger one in India, but the Chartrain dam is very high. It is the last expression of the French practice in dams.

The Bouzey dam is totally different in shape and structure, and a great quantity of work is utterly thrown away. The Chartrain dam is very short, but very high.

Mr. William Brodie said—I did not attend to-night prepared to speak, for, despite the President's kind assumption that the members present were masters of the subject, I for one feel that in familiarity with it the President and the author of the paper hold a great advantage.

There is, however, a point in connection with the Bouzey dam which Mr. A. G. Lyster, who unfortunately is not able to be present to-night, has asked me to put forward with a view to eliciting the views of members. After all, the Bouzey dam question was in the minds of all who listened to the author's able paper, overshadowing its other interesting points. On the construction of dams generally I am sure that the members will agree that if they had a dam to design and followed Mr. Brightmore's rules they might sleep secure on the lower side of the dam when erected.

Reverting to the Bouzey dam, it is a somewhat startling fact that important dams have been constructed in comparatively recent times in France of such widely different character as the dam which failed, and the others which the author illustrated and mentioned as the last word of the French engineers on the subject, although, as the President explained, the Ponts et Chausée's men were not responsible for the original Bouzey structure. The reasons given for the failure of the Bouzey dam were very numerous and various, but none of them brought out the point to which Mr. Lyster wished to refer. The dam, as originally built, was, no doubt, weak but of fairly uniform elasticity. The large buttress, which was put in with the idea of saving the dam, stiffened the lower part of it very much, but conveyed no strength to the upper part. As Mr. Lyster says, it puts the dam, as a whole, practically into the position of a fishing rod with a very heavy butt and a light top and no intermediate lengths, and which, consequently, is in an unfavourable position to stand the stress coming upon it because of the unequal elasticity of the several parts, and that that may have something to do with the failure is, he considers, borne out by the manner in which the dam failed. He is led to think in that direction from the fact that in some of the walls that have recently been constructed on the Dock Estate—good, strong walls built in trenches, whereby for a time they are maintained stiffly in position by shores to adjacent banks, when the banks and struts are cleared from part of the wall—a crack sometimes appears where the wall is held stiff. There is in this case no question of expansion or contraction, but failure is due probably to the fact that there is sudden rigidity at one point.

Mr. A. Hope said—In the early part of the paper the author states that the resistance to shear in any horizontal plane shall be greater than the total horizontal thrust of the water above the level of that plane.

I should like to ask the question why no factor of safety is mentioned in the case of shear, whereas in the case of compression it is generally arranged that not more than 10 ton per square foot shall be allowed on the masonry.

It seems to me conceivable that the shearing stress on some of the sections of the dam might bear a much greater ratio to the ultimate shearing strength of the masonry than is permitted in the case of compressive stresses, but possibly investigation will show that this is not so and that the margin is ample.

Mr. C. H. Darbishire said—I notice in the paper with regard to

one point that the author does not explain how the specific gravity of the material comes in.

It seems to me that possibly the specific gravity of the material is a very great point in the solidity of the dam, because possibly the weight of the material put in helps to resist the strain of the water which it has to uphold.

Mr. Coard S. Pain said—I rather gleaned from the author that in dealing with the power of resistance of the dam, nothing is allowed for its connection with the sides of the lake or whatever it may be, and I should like to ask whether that same view may be extended with reference to the question of adhesion at the base to prevent slipping. If so must we understand that a dam has to be constructed so that its own weight will resist the pressure it has to bear?

Mr. A. W. Brightmore, in reply, said—I ought to have stated that the dotted lines show the lines of resultant pressures when the reservoir is empty and full. That these lines should come within the middle third is the whole point.

In the case of the Bouzey dam, the dotted lines represent the points of application of the resultant weight and of the resultant of the weight and the pressure of water in the final stage of the dam, when the buttress was added on the lower side. The outer dotted line comes well without the middle third of the breadth for a considerable height of the dam. That of course is the reason why the tension is brought in at that part.

With regard to Mr. Brodie's view, which I understand is, that as an elastic structure the Bouzey dam would probably have stood, whereas by making it a rigid structure it was not strong enough to stand owing to the tension introduced. There seems to be something in that method of looking at it, but masonry dams ought to be designed to stand as rigid structures, without having to trust to this elasticity for preventing a disaster. However, I think it is very probable that, as Mr. Brodie points out, the fact of strengthening the lower part and making it perfectly rigid would have something to do with the upper part giving way.

Referring to the question raised as to the factor of safety in shearing, the factor is greater than in compression, that is why no stress was laid upon it.

Regarding the specific gravity of masonry, this is the most important property of the material selected for a masonry dam. It is entirely due to the weight of the material that the pressure of water is resisted. It is easy to see if, for a moment, it is considered that the water is

tending to turn the dam about its outer toe, that the heavier the material is the greater will be the resistance to the pressure of the water.

Mr. Pain alluded to the adhesion at the sides and bottom. I may say that the foundations are not called upon in the calculations to resist any tension at all, but only the shearing and compression stresses in the former of which, as I have just stated, the factor of safety is very considerably more than for the compressive stress.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

TWELFTH MEETING—13TH APRIL, 1898.

JOHN A. BRODIE, Wh. Sc., M. Inst. C.E., M. I. Mech. E., VICE-PRESIDENT, IN THE CHAIR.

The following candidates were duly elected to the Society, viz. :—Messrs. A. F. FOWLER and H. H. STRONGITHARM as *Members;* Mr. J. EDMONDSON as a *Student.*

The nomination of Council and Officers for the ensuing session resulted as follows :—

President—JOHN A. BRODIE.

Vice-Presidents—

A. BROMLEY HOLMES. J. A. F. ASPINALL.

Members of Council.

J. WEMYSS ANDERSON.
MALCOLM BLAIR.
WILLIAM BRODIE.
G. L. BURTON.
F. E. COOPER.
C. H. DARBISHIRE.
ROBERT F. HARVEY.
THOMAS DUNCANSON.
ROBERT E. JOHNSTON.
WILLIAM E. MILLS.
THOMAS L. MILLER.
JAMES MORGAN.
FRANK E. PRIEST.
J. RENEY SMITH.
HENRY H. WEST.
ERNEST S. WILCOX.
JOHN T. WOOD.

Hon. Treasurer—COARD S. PAIN.
Hon. Librarian—ARTHUR MUSKER.
Hon. Secretary—R. C. F. ANNETT.

LIVERPOOL LANDING STAGE EXTENSION AND PRINCE'S JETTY.

By HUGH ROGERS.

I PROPOSE this evening to give you a short account of the works in connection with the extension of the floating stage, but more particularly of the Prince's Jetty.

In extending the Prince's stage to the northward, provision had to be made for protecting the structure from vessels using the south entrance to the Prince's half-tide dock, and the Prince's Jetty serves this purpose as well as that of giving a fair lead to the dock entrance, and affording a berth for landing cattle and cargo from the coasting boats.

The first and foremost use of the jetty was purely a protection to the stage, but it was afterwards decided to make it available for landing cattle and cargo from the coasting boats, and so give extra accommodation to the stage.

For this purpose four decks were provided, each with runways for cattle, and stairs for the passengers leading to the street level. The total length of the jetty is 400 feet, and 67 feet wide. The main timbers of the structure are all greenheart, the uprights being 14 inches square, and varying in length from 47 feet to 76 feet 8 inches. The cross braces are 12 inches by 6 inches, and the diagonal bracings 12 inches by 12 inches. The joists of the decks are all of creosoted pitch pine, and the deck is of greenheart, 3 inches by 4 inches, spaced half-an-inch apart. At this point of the river the bed is of red sandstone rock of a hard close nature, varying in depth from about 12 feet below old dock sill at the river wall to about 40 feet below the old dock sill on the face line of the stage. Along the river wall, and for a width of about 50 feet, a bank of stones, boulders and the like have evidently been tipped, possibly at the time the river wall was built, but more probably to protect the toe of the wall. The stone found here was of many different kinds, but principally composed of large blocks of sandstone, large boulders of the nature of Penmænmawr stone, also a quantity of coarse gravel, but very little sand, and occasionally bits of old iron in the shape of plates, anchors, and chains.

The tide at this point is very strong, which was a serious point to be considered in the method to be adopted of obtaining a suitable foundation. The ordinary system of tide-work dams would have been most expensive, both on account of the tide and the depth of water, and also on account of the river traffic at this point. Screw piles were also considered, but as this entailed boring and blasting in order to get a hold for the piles, this system was given up. Mr. Lyster finally decided to adopt some form of drill with which to form pockets in the rock, and then to grout the uprights into these pockets with concrete. Work of this description had been done at Newcastle for the foundations of the piles forming the dolphins at the coaling staiths, but in this case a 3-inch hole was jumped into the rock, and into this hole a 4-inch square spike about 6 feet long was driven, which formed part of the pile shoe. The boring for these piles was all done off the deck of a flat, so that the work could only be carried on in fine calm weather. To avoid all such stoppages it was decided to do all the work from a platform which could make its own ground, as it were, and travel on it. It was also decided to form a hole large enough to take the pile itself instead of trusting to the straps of the pile shoe only, as in the case at Newcastle. For this purpose a drill was obtained which was capable of drilling a hole 25 inches in diameter. This drill was a diamond rotary drill driven by belting off a 20 horse-power engine, a class of drill largely used for deep borings for water or coal, but hardly suited for shallow borings or work in a tide-way, where it had to contend with all sorts of foreign matter other than red sandstone. And as this drill had to be mounted on an overhanging frame its weight was very much against it, it being fitted with a quantity of heavy gear, which was quite unnecessary for work of this kind, such as a heavy winch capable of lifting 20 tons, three different speeds, and brakes to all movements. The whole of this machine, which weighed about 20 tons, was mounted on a steel carriage provided with castor wheels, arranged to travel in any direction with the wheels having their bearings on the three back sections of piles, and the centre of the drill working ahead for another section. The drill itself was also mounted on wheels, so that after the carriage had been brought into position, the drill could be adjusted to its exact working place.

To protect the boring rods from the action of the tide, guide pipes were provided; these were wrought steel tubes 25 inches internal diameter, in handy lengths of 5, 10 and 15 feet, and flanged for connecting to each other. These pipes were also necessary to protect the drill from foreign matter in the shape of stones, &c., getting in and

choking the drill; for this purpose the pipes were fitted with a steel crown of serrated teeth, and with this crown the pipes were screwed down into the rock. This crown however soon wore away, and had to be replaced by one of mild steel into which mushett steel teeth were fastened, and which could easily be replaced when worn. The pipes themselves were stayed to the main structures by angle iron guides. The first operation after the carriage had been moved into place, was to lower these guide pipes into place; this always had to be done at low water, otherwise they could not be held in place. The drilling machine was then attached to these pipes, and proceeded to bore them down through the overlying surface to the rock, but this was a very difficult and slow process to carry out on account of the nature of the overlying stratum, which had to be either removed or broken by blasting. When the pipes were down into the rock, the diamond drill was lowered down inside and drilling commenced. The drill itself was a cylinder about 10 feet long, divided into two halves, the upper half being used as a sediment tube into which the sandstone powder, which was ground up, settled and was collected, being afterwards cleaned out through a door at the bottom of it. The lower portion was fitted with a mild steel crown 24 inches in diameter into which the diamonds, 40 in number, were set. These were Brazilian black diamonds, the largest weighing from 6 to 7 carats. They were set first of all in small steel plugs on a copper bed, and then these plugs were caulked into the face of the crown. The diamonds were set in eight groups of five, a waterway being cut between each group.

The cylinder was connected to the machine by 4-inch hollow boring rods of mild steel in 5-foot lengths, and coupled together with steel screw sockets. These rods were also used for the water supply for keeping the drill clear, a continuous flow of water having to be kept on at a pressure of 10 pounds to the square inch.

If once the sandstone were reached, and could be kept clear of foreign material, such as gravel and small stones, the drill worked most satisfactorily, boring about 10 inches per hour; but on account of faults in the rock it was a most difficult matter to keep this foreign material from working in under the pipes. These either jammed the drill and the pipes, or else got under the drill and acted as rollers, or between the drill and the core and broke the latter up, or stones of an eccentric form getting under the drill would lift it up, and in falling, the diamonds got cracked and broken. When, however, a hole was successfully bored a core would be left standing inside the drill, and when the proper depth had been attained a few

small pieces of broken bricks were put down through the boring rods into the drill, and jammed between the drill and the core by water pressure. A few revolutions of the drill broke the core off, and it was brought up in the drill. If however it did not hold, a grab had to be put down to bring it up. This grab was attached to the boring rods, and when once it got hold could be screwed up to grip the core.

After a very patient trial of several months it was decided to abandon this drill and adopt other methods.

For work of this description such a drill was too fine, and unsuitable for the rough work that it had to face, besides being a very expensive tool, both as to first cost and also for working. Had the rock been clean, with no over-lying foreign matter near, I have no doubt but that it would have worked well, but what with the continual stoppages to draw the drill and clean the hole out, the cost of the broken diamonds, and the excessive weight of the machine, it proved to be unsuitable for the work required of it.

The next method adopted, and one which proved most successful, was jumping the holes down with chisels. On account of the size of the holes required it was not easy to obtain much information as to the best style of chisel to adopt. Some work of this class is done by surging with a wire rope heavy castings set with interchangeable steel cutters, or by chisels weighted with heavy sinker bars 6 inches in diameter and 10 to 20 feet long, according to requirements. Most of these tools are worked by a wire rope leading over a lead block on a pair of shear legs, and then taken either to a steam winch, off the barrel of which the weight is surged, or else the wire rope is attached to the piston rod of a steam cylinder. The best class of chisel had consequently to be obtained by experience, the first set used being ordinary flat chisels in three different sizes, the small one being 11 inches, the next 18 inches, and the third 24 inches wide, all fitted with side wings. It was found that to put a solid 24-inch chisel down straight away without first making a smaller hole, caused so much vibration through the chisel rods that they were continually breaking. This form of chisel would be a very satisfactory one for a contractor working day work.

The design of chisel finally adopted was a flat blade of wrought iron, with a cutting edge of steel about 6 inches up, and fitted with detachable wings. The centre portion of this chisel was cut away for a width of $8\frac{1}{2}$ inches, and about 18 inches high, making the cutting surface $15\frac{1}{2}$ inches, thus reducing very considerably the vibration caused

by the blow, and the small core which was left standing was soon broken off with the jar of the blow. This chisel weighed about 10 cwt., and was connected up with boring rods of different thicknesses, varying from $2\frac{3}{4}$ inches square to $1\frac{3}{4}$ inches, the lower rods having guides fitted to them for working in the centre of the pipes, and to prevent vibration as far as possible. The rods themselves were connected to the piston rod of a 9-inch steam cylinder, placed vertically on a small carriage overhead, so that it could be moved out of the way for pumping out, &c. This cylinder was only used for lifting the rod, steam being applied to the underside of the piston rod only, the actual weight of the chisel and rods striking the blow; the total weight being about 30 cwt. The connection between the rods and the cylinder was a flexible one, and not a rigid connection, a 3-inch rope tackle being used for this purpose rove through swivel blocks on the top of the rods and the bottom of the piston rod; the fall being made fast to the tillers attached to the top of the boring rods, which were used for turning and tightening the rods after each blow. This rope tackle was also used as a feed for lowering out the rods as the hole increased in depth. The average number of blows delivered was 25 per minute in hard rock, but in softer rock it varied, as frequently the chisels jammed, and the blows had to be regulated in strength.

The sandstone, which was broken up into fine sand, was pumped out of the holes by means of an 18-inch sludge pump working on the end of a wire rope. This pump was a cylinder 10 feet long and 18 inches in diameter, with a rubber clack at the bottom, and having a plunger working inside to which the wire rope was attached. This was a most successful pump, and was capable of bringing up stones 10 and 12 inches in diameter.

This system also did away with the time occupied in screwing down the pipes as in the case of the diamond drill, for the pipes always followed the chisels down until the rock was hard enough not to fray away with the jar of the blow. These pipes have followed the chisels down through as much as eight feet of over-lying stones, &c. Another great advantage in this system was that the gear took up so little room on the working stage that two sets of holes could be worked at once, as against only one with the diamond drill.

The operation was briefly this. The pipes were pitched in position as in the case of the diamond drill. The sludge pump was then put down to bring up all the smaller loose stones and gravel; this operation alone used to take the pipes down about two feet. After all the small

stones were brought up, a chisel was put down to break up some of the larger stones until the rock was reached, when the hole would be pumped out again so as to give the chisel a chance to work on the clean rock without any hard obstructions. The chisels would sometimes do as much as six feet before it was necessary to pump out, but about three feet was quite sufficient to cut down without pumping, as a cleaner cut was got when the hole was free from sediment. As a general rule 12 inches an hour was a fair average to take for boring, including pumping out. At times exceptionally hard strata of the rock would be met with, when only three or four inches an hour could be done, but as a rule the drill would work down about 16 inches per hour. After the hole was bored to the required depth and cleaned out, the pipes would be disconnected at a suitable joint and at as low a level as possible, and the upright was shipped into its proper position inside the pipes, and was then grouted in with concrete, which was run down a 3-inch pipe inside the guide pipes. These uprights at the outer end of the jetty were about 75 to 76 feet in length, fully two-thirds of which length was inside the pipe, so it was a difficult matter to get the uprights perfectly plumb, which was necessary as far as possible, as each section of the jetty was built together first before these were placed, consequently the uprights had to be as exact as possible so that the bolt holes would come in, the bottom ones especially, as these had to be put in by divers. As regards the boring there was no divers' work required, all the work being done from the stage above, the only divers' work being the fixing and bolting of the lower ends of the bottom diagonals and chocks.

As regards the extension of the floating stage, the design of this length of 400 feet is practically the same as the old Prince's stage, only slight alterations being made in the details. The new portion is carried by 27 pontoons, 23 of which are 80 feet long by 10 feet wide and 5 feet deep, the remaining four being 96 feet long, this extra length being provided to carry the foot of the bridge connecting the stage and jetty. These pontoons run transversely to the stage and carry the kelsons, which run longitudinally. These kelsons are box girders composed of iron plates and angles, and are 4 feet 6 inches in height, and across these again are the deck beams, also of iron. The pontoons were put together in Birkenhead. They were tested for tightness by being first filled with water, and afterwards by the external water pressure due to their own weight. Each pontoon has three watertight bulkheads. After receiving three coats of red oxide paint, each pon-

toon was launched into the west float, and then was towed across to the opposite side of the dock to where the kelsons were being erected. These were placed on the pontoons in 39-foot lengths, and subsequently all riveted up together with the deck beams.

When completed the whole was towed across to Liverpool and put into position, and the connections with the old kelsons riveted up. For this towing four tugs were employed, and they brought the stage over at slack water just before low tide, leaving sufficient run of tide to sheer the stage into place. Before the stage arrived, the northernmost boom (No. 6) of the old stage had to be moved further north so as to be ready to be landed on the new stage to hold it in its proper place, and as there was not room for the floating crane to get out between the end of the stage and the jetty, this had to be done beforehand. To hold the stage end of the boom, a flat was moored in position in the river, and a cess of timber was built up on her deck, and on to this the boom was landed 12 feet from the stage end. After the stage was in place this flat was sunk low enough for the boom to take its bearing on the stage end pivot. A second boom was put in later, and as the entrance to the back of the stage was altogether blocked for any craft capable of lifting such a weight, it had to be landed on the river side of the stage, and launched across on to two flats which held it over its position at high water, and as the tide receded it found its bearings first on the shore pivot, and at low water on the stage bearing. The same flats were utilized to put in the four ebb moorings and the two flood moorings, composed of 2-inch open linked chains. The decking of the stage was done after the kelsons had been riveted up. This consisted of 12 inches by 4 inches creosoted pitch pine foundation timber laid across the deck beams, and bolted to them with $\frac{5}{8}$th-inch bolts, and laid half-an-inch apart. This differs from the foundation of the old stage, which is of greenheart with caulked seams. On the top of this foundation a sheathing of greenheart 6 inches wide by 2 inches deep was laid, and held down with 4-inch ragged spike nails, all the joints being caulked. As an experiment, and for a better foothold for horses, a strip 30 feet wide for the full length was laid with end on blocks of creosoted pitch pine, 3 inches wide and 3 inches deep, the joints being run with pitch and fine gravel. The bridge connecting the stage and jetty was erected on the north end of the stage, and when completed was launched into position. The bearing for this bridge on the jetty is composed of a steel axle working on a cast-iron pivot, and cast-iron bearing block, the stage bearing being two half-round cast-iron shoes working on cast-iron slides. The length

of this bridge is 152 feet by 21 feet wide over all. The total length of the Liverpool landing stages is now 2463 feet, and the normal width is 81 feet 4 inches, having a deck area of 23,098 square yards or $4\frac{3}{4}$ acres. The whole stage is floated on 180 pontoons varying in length from 60 feet to 120 feet. It is approached by 8 bridges, and is kept in position by 7 booms and 29 mooring chains (14 ebb chains and 15 flood chains). In addition to the 7 bridges, there is a floating roadway 550 feet in length and 35 feet in width.

LIVERPOOL ENGINEERING SOCIETY.

TWENTY-FOURTH SESSION.

ANNUAL MEETING—27TH APRIL, 1898.

GEORGE FARREN, J.P., M. Inst. C.E., F.R.S.S.,

PRESIDENT, IN THE CHAIR.

The Annual Report of the Council and Hon. Treasurer's Statement of Accounts were read and adopted.

The election of Council and Officers for the ensuing session resulted as follows:—

President—JOHN A. BRODIE.

Vice-Presidents—

A. BROMLEY HOLMES. J. A. F. ASPINALL.

Members of Council.

WILLIAM BRODIE.
F. E. COOPER.
C. H. DARBISHIRE.
THOMAS DUNCANSON.
THOMAS L. MILLER.
WILLIAM E. MILLS.
JAMES MORGAN.
FRANK E. PRIEST.
J. RENEY SMITH.
HENRY H. WEST.
ERNEST S. WILCOX.
JOHN T. WOOD.

Hon. Treasurer—COARD S. PAIN.

Hon. Librarian—ARTHUR MUSKER.

Hon. Secretary—R. C. F. ANNETT.

DIAGRAMS AS ILLUSTRATING SHIP AND ENGINE PERFORMANCES.

By ANDREW HAMILTON, M.I.N.A.

WITH graphic methods of representation we are becoming more familiar every day, even the monthly magazines are educating the general public, while the members of the Statistical Society are doing excellent work in this direction. Graphical arithmetic and statics are now common subjects in our schools, but it takes considerable time for such new ideas to "catch on" in (say) shipping circles.

James Hamilton, Esq., of Messrs. Napier & Sons, in his paper, "The Speed and Form of Steamships considered in relation to length of voyage," which was read before the Institute of Naval Architects, in 1883, was one of the earliest to suggest laying down the relative performance of ships, and later, in 1887, Robert Thompson, Esq., of Sunderland, at the North East Coast Institute of Engineers and Shipbuilders, on the "Influence of Coal Consumption on Commercial Efficiency, and the design of Cargo Steamers."

Since that time graphics have been gradually gaining in favour in all departments of ship and engine designing and working.

The following diagrams have been found useful as illustrating performances under varying conditions of time, &c., thus forming a basis of comparison or balance sheet.

Those who have the care of ships or engines in constant working know how essential it is to keep the whole in a high state of efficiency, including the human element. At the same time we are never allowed to forget that the engines and boilers in a ship are only a means to an end, and the whole vessel supposed to be a dividend producing machine. It is here that the great advantage of diagrammatic representation comes in, as it rarely falls to the engineering department to discuss the profit and loss account, but, being one of the largest spending departments, it is of the greatest moment to be able to show what is being done, be it cost of increase of speed, cost of short spurts to make ports, or the influence of weather on speed, &c., so that the owner with his full knowledge of freight and charters available may make the best use of his property.

Diagram No. 1. Proportionate expenditure.

This gives a general statement of the disbursement in some steamers of 3000 ton dead weight.

APPROXIMATE AMOUNTS.

	Per Cent. of Total Expenditure per Annum.
Coals	11 per cent.
Engine Stores, Oil, &c.	2 "
Machinery Repairs	2 "
Deck Stores, Sundries, &c.	2½ "
Light Dues Pilotage	12 "
Brokerage and Stevedoring	26 "
Insurance	17½ "
Depreciation	9 "
Wages and Provisions	18 "

Outside is a circle put at 10 per cent. profit on capital to complete the balance sheet. The whole being total receipts.

Each or any of the above items may form the subject of a diagram from year to year, or voyage for one or several vessels.

The superintendent engineer has the coal bill, engine repairs and stores to face during running, also keeping depreciation as far away as possible, reducing risk of breakdown to machinery, and sustaining credit of the risk to secure the best terms for insurance; while the naval architect has his work at the building of the ship in designing generally, to keep down tonnage for dues, &c., handiness for stowage and bunkering, and structional strength for intended trade.

The second diagram illustrates somewhat how small a proportion of the total heat is effective in the engine, at the same time showing in what direction economies are possible. In making improvements it has to be borne in mind the number of days a steamer is at sea in which the return on capital and depreciation must be earned on any extra outlay.

This diagram forms a most interesting study, and may with advantage be amplified; the total thermal units, the product of the combustion of one pound of average Welsh coal, is divided approximately as follows:—

Condenser disposes of 61 per cent. when engine is working at 80

pounds per square inch pressure, and 57 per cent. when at 200 pounds per square inch pressure.

Engines use 11 per cent. at 80 pounds pressure, and 15 per cent. at 200 pounds pressure.

Radiation from boilers shown at 8 per cent. increasing with the steam pressure.

Funnel gases are 18 per cent. average, and also increasing with the pressure.

Ash (say) 2 per cent.

Though there is such a small percentage of the total heat of combustion used in the engine, it always appears some consolation that we have only to carry $\frac{1}{20}$th of the elements necessary, as, off and on, 19 tons of air are used per ton of coal; therefore, any electric installation to displace the steam engine on board ship must use chemicals in the end cheaper than coal and air.

The actual expenditure of coal for any particular ship varies considerably, depending on the quality and actual quantity received. In the main it can be shown, as in the third diagram, approximate consumption of coal per day for different classes at any speed in average weather. Here the consumption is given for a 9000 dead weight carrying steamer, for Welsh, Newcastle and Calcutta coals. The fourth gives expenditure in pence per knot for repairs and stores; the repairs taken over some 54,000 miles per annum, enables one set of engines to be compared with another of the same or other builders.

Stores taken over similar mileage show variations from year to year, sometimes due to reduction in prices, but very often with change of staff, one man making better use of the material than another. It by no means follows that the best kept engine department is the heaviest in paints, &c., but rather the reverse, and *cleanliness* does certainly *not* add to the repair bill.

The fifth diagram illustrates what the increase in dead weight ability of the vessels, increase of pressure and improved design of engines, &c., has done to reduce coal consumption. While the speed of the vessels given increases from A to C, the others are almost constant, but with the larger ships the coal per 1000 miles has rapidly diminished, or taking the total displacement it is progressive throughout.

The reduction of coal per 1000 knots per 1000 tons cargo carried being the end in view, it will be noticed the earlier ships, if run now, are handicapped in several ways not least by their own greater weight per ton dead weight.

The effect of weather on a ship's speed gets credit or discredit for a

great deal, sometimes more than it ought, yet when carefully gone into, it can be shown to be the cause of some failures to realize reasonably expected speed at sea.

The sixth diagram gives a typical colonial voyage out and home, the speed of the ship is dotted lines, and speed of engines shaded.

In (say) 48 days run out, 10 days at 8·5 knots due to stress of weather, would involve for the remaining 38 days, 10·4 to give a 10-knot average (and as we know it is the last half knot that pinches and not always attained), that is supposing the bad days occur early on the voyage, and that increase in consumption of coal is prudent and possible. Thus the graphic logs carry conviction with more and greater clearness than any number of figures, which are apt to remain unread.

Diagram seven is somewhat of the same character as used in making up railway time tables, and is useful in so far as it shows the position of ships of any "line" in relation to each other, and when closely posted enables the management easily to keep in touch with the ships for shore business, &c.

Diagram No. 8 is somewhat similar to that proposed by James Hamilton, Esq., in his paper before mentioned.

The most profitable speed to steam at is a very present question, and here again it appears to be helped by the graphic statement.

Referring to the diagram, the speeds are given at the bottom for a steamship 10,000 tons, and one 6000 tons dead weight ability.

The cost of running and earning is per day (a week or year might be taken, but care is necessary with the varying speeds to bring all to the same terms of time).

The basis in this case being taken as the time required to run 52,000 knots, including 165 days in ports, discharging, &c.

The lower full and dotted curved lines give the total expenditure per day, including items detailed below:—

(A) Speed reducing, increased number of days required for distance, also, more time allowed for ports due to greater amount of cargo.

(B) Insurance, depreciation, wages, food increasing, with reduced speed.

(C) Coal consumption coming down with reduced speed.

(D) Harbour, canal and light dues and pilotage diminishing with speed, being less often in port in a given time.

(E) Brokerage and stevedoring increasing with speed, but chiefly depending upon amount of cargo carried.

The upper full and dotted lines represent freight, the total reducing at higher speeds as more coal is carried shutting out cargo.

Measuring then the distance between the two full lines, the most profitable speed in this case for the 10,000 ton carrier is 10 knots, while in the smaller steamer, 6000 tons dead weight, a knot less is most economical.

This line of investigation can be gone into much further, as the form of the vessel affects the results materially, a finer coefficient not necessarily reducing in the end the carrying capacity.

Ninth diagram represents profit and loss account, the last and no doubt the most important.

S.S. "A." First cost £10,000.				S.S. "B." First cost £100,000.			
1st year's dividend,		11	per cent.	1st year's dividend,		14	per cent.
2nd	" "	4	"	2nd	" "	11	"
3rd	" "	6	"	3rd	" "	$5\frac{1}{2}$	"
4th	" "	$1\frac{3}{4}$	"	4th	" "	10	"
5th	" "	2	"	5th	" "	40	"
6th	" "	7	"	6th	" "	15	"
7th	" "	$8\frac{1}{2}$	"	7th	" "	9	"
8th	" "	$4\frac{1}{2}$	"	8th	" "	10	"
9th	" "	$1\frac{1}{2}$	"	9th	" "	25	"
10th	" "	$3\frac{1}{2}$	"	10th	" "	5	"
Sold at end of 10th year for £5,000.				Sold at end of 10th year for £60,000.			

The two diagrams are constructed alike, only the capital in the S.S. "A" is one-tenth of that in the S.S. "B," and both ships were run by their respective firms for 10 years and then sold.

The base gives the age, and the capital line is drawn parallel, with a line rising above representing natural increase, if the money were invested in Liverpool $2\frac{1}{2}$ per cent Corporation Stock, simple interest; that interest line is used for setting off dividends or loss from ship's trading.

The depreciation line is drawn at 5 per cent or 6 per cent (more is often necessary), and is calculated on the reducing capital, but no allowance is made for reduction in value on account of cheaper production of tonnage, which, in the last 10 years, has been from 15 per cent. to 20 per cent.

Thus it follows that the venture to be fairly remunerative must give returns which exceed the natural increase of ordinary investments and percentage of depreciation. In the case of the steamer A, the whole transaction turns out a loss, but not so by any means the steamer B; in the latter, the first cost or capital was returned at the end of the eighth year, the ship was sold and paid in addition 60 per cent. upon her original value.

The methods shown appear to have a future in their development, as a means of enabling many problems to be rapidly and accurately solved in connection with steamships.

The increasing competition among shipbuilders, and rapidity of production of new vessels, demand that the shipowner should know what is most suitable before fixing the contract on a dead weight basis, as is common now, and this seems only to be possible by the mutual examination of the costs and influence of the design of the steamer; so that, even with the vanishing freights, a profit may be realised.

It is hoped that this short paper will stimulate discussion, and that the members will consider and suggest some other points and methods of illustration.

NOTE.—The Discussion on this paper was adjourned to an early Meeting of the XXV. Session.

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ROYAL INSTITUTION, COLQUITT STREET.

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